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SYMPOSIUM PROCEEDINGS

GIS 90

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"MAKING IT WORK"

GIS '90, an International Symposium on Geographic Information Systems, is co-sponsored by Forestry Canada and Reid, Collins and Associates.

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GIS
90

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"MAKING IT WORK"

This volume contains the text of papers presented at GIS'90, arranged thematically.

Managing Resource Conflict

GIS Applied to Harvest Planning
DEMs: Visibility Analysis
GIS for Agricultural Planning
GIS for Park and Recreation Management
Decision Support Systems
GIS for Fire and Pest Management
GIS for Wildlife and Habitat Management

Making GIS Work

We Did It Our Way - Making a GIS Usable
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How We Share the Data
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Management Issues and Perspectives in GIS

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Data Structures
Data Issues
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GIS as a Canadian Export: Panel Discussion *no papers*
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Artificial Intelligence
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Ministry of Forests of British Columbia: Panel Discussion *no papers*

"MAKING IT WORK"

Edited by **Charles Goodbrand**

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in collaboration
with **Paddy O'Reilly**

Polaris Learning Associates, Inc.
GIS'90 Symposium Manager

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Notes

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Managing Resource Conflict

Session A1
GIS Applied to Harvest Planning

Stand-based Timber Supply Modelling

A Forestry GIS Pilot Project for Interior BC

Woods Production Planning and Inventory System

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Integration of GIS and Wood Supply Modelling

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Abstract
Harvest planning can be an expensive and time consuming task in the overall timber management planning process. In a joint research project with Abitibi-Price, Iroquois Falls, Ontario, the author has developed an interactive harvest planning tool. The system integrates stand-based timber supply modelling and GIS. The author will describe the techniques used and the results.

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A Forestry Geographic Information System for Interior British Columbia: The Industrial Forestry Service Ltd. Pilot Project

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Abstract
This paper describes a geographic information system (GIS) pilot project in the northern interior of B.C., illustrating the application of GIS to harvest and silviculture administration. The system is intended for GIS users of limited experience. Emphasis is placed on current and proposed information products using current data. The applications developed illustrate interactive querying of the GIS and the generation of tabular reports with the help of these queries. The pilot project illustrates the ability of GIS to fulfil present and near future needs for tabular and spatial information products. A schedule for development of applications over the coming year is discussed and general comments on the process of GIS implementation are made.

Introduction

There has been an increased need in recent years for accurate and timely information in natural resource management. This need has been defined by:

(i) the public and its government, who want better stewardship of their natural resources and,
(ii) the forest industry, who with increased responsibilities want to be more cost effective and productive.

To satisfy this information need, it became necessary to search out an appropriate system to use, and to structure, organize and implement it.

Geographic information systems (GIS) provide us with a system capable of managing our spatial (where) and attribute (what) information. While GIS may provide us with 'the system' to use, we don't yet have a map of how to structure, organize or implement it. As this conference theme, 'Making it Work' implies, there are still several problems to iron out.

This past year, Industrial Forestry Service Ltd. (IFS) began a pilot project to provide GIS services to the British Columbia interior forestry community. This paper will:

(i) describe IFS,
(ii) outline our strategy for GIS development,
(iii) present our progress to date, and
(iv) present our plans for further development in the next year.

The paper will conclude with comments on the process as we have experienced it and as we see it into the near future.

Background

Company Profile

Founded in 1952, IFS provides high quality, competitively priced services to the resource industries of British Columbia, Alberta and the Yukon. These services include general forestry and silviculture consulting, forest seedling production, engineering, photogrammetry, and recently GIS.

Our path to GIS has come from both forestry and photogrammetry. In addition to the traditional forestry services, IFS has carried out digital base mapping since 1985 at scales from 1:500 to 1:50 000. In 1987 IFS produced the first Terrain Resource Information Management (TRIM) map for the Province of B.C. The Company also developed the quality control system and helped develop specifications for TRIM mapping. Presently, we run four digital stereoplotters to capture three dimensional geographic data. Three graphic computer stations are used for editing, with attribute information supplied by in-house photo interpretation and field crews. This past year, IFS completed production of 120 TRIM maps, re-inventory and production of 170 maps for the B.C. Ministry of Forests and completed the re-inventory and production of 90 maps for Westar Timber's Tree Farm Licence (TFL) number twenty-three data loading.

In 1988, IFS bought ESRI's ARC/INFO GIS software. ARC/INFO has been acquired by five provinces and many forest companies since its creation in 1982. It provides a flexible data structure, powerful spatial analysis capabilities and the Arc macro language (AML), a macro language giving the ability to develop specialized, powerful applications. At IFS, ARC/INFO runs on a Digital Equipment Corporation MicroVax 3600, dedicated to GIS. A staff of ten look after editing and final production of maps using in-house developed, menu-driven AML software.

GIS Development Strategy

With our experience in digital mapping and forestry, and the forestry community's curiosity in GIS, IFS explored the possibilities for providing GIS services to its clients. As could be expected, the forestry community is cautious, in addition to being curious, about GIS. Although forestry personnel are certain that GIS can make their lives easier, upper management is sceptical about the cost effectiveness of GIS. As a consulting company, this left us in a quandary: no clients, no development; no development, no clients. Because of the confidence IFS has in the use of GIS in forestry, we assumed the risk and began plans for GIS development, in consultation with interested, traditional clients.

Meetings with these clients lead to the specification of the GIS environment within which GIS development occured. The criteria defining this environment are:

(i) hardware, including the main computer and storage is provided by IFS,
(ii) the GIS database structure is common for all clients, and
(iii) the in-house developed software for GIS access is common to all clients.

Customization for specific client applications can be accommodated at a later date. This organizational framework allows clients to use the IFS computer as their computer, or as a file server to their workstation. If clients wish to transfer their data to another computer system/GIS, we will translate the data into the required format.

Development of GIS services at IFS is targeted at supplying clients with a powerful GIS and technical support at a fraction of the expense of owning and operating a full system with similar capabilities themselves. IFS is responsible for data security, software development and hardware/software/data maintenance. All data are kept at IFS and the database is structured so that only the client, or IFS, with permission, can access that client's data. Three access routes to the GIS are planned:

(i) by IFS personnel at IFS,
(ii) by clients at IFS, and
(iii) by clients at their own offices.

To use the last route, clients will need to buy their own remote station.

With this much decided, the problem now lay in exactly how to implement a GIS. To explore this, a pilot project was undertaken. Rustad Bros. & Co. Ltd. assisted with the project by providing data for their Barton Lake Forest Licence Chart Area and personnel to guide development.

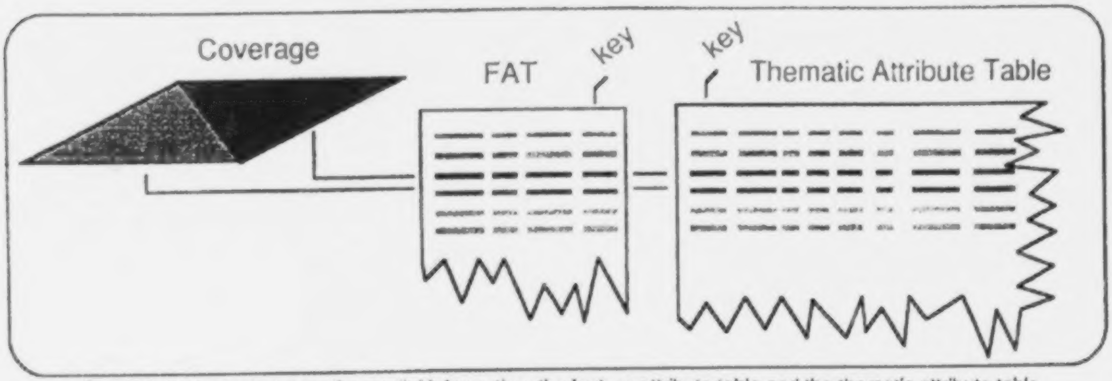

Coverage
FAT
key
key
Thematic Attribute Table

Figure 3. Linkages between the spatial information, the feature attribute table and the thematic attribute table.

As an example of how the data are organized, Figure 4 illustrates the information linkages used in developing a pre-harvest silvicultural prescription.

Loading Data

Problems arose once the loading of data began. As is typical, there were no problems with what we created the database to handle, however there were problems with interpreting data for entry into the GIS. While digitizing from existing field maps and chart area maps, it became apparent that the accuracy of the spatial data was critical. For instance, a site preparation treatment unit boundary roughly follows the edge of its cut block boundary, which roughly follows the edge of a stream. If all three boundaries are really common, then the line should be digitized only once (the stream) and copied into the other coverages for use. But what if the site preparation didn't really go to the edge of the cut block or if the stream is in the bottom of a steep ravine, and the cut block boundary is close to but not on the stream edge? With the entry of data into the GIS, it will become increasingly important that field personnel make sure that field maps communicate their information effectively.

When the pilot project began, the personnel at Rustad Bros. wanted to enter attribute information, in our format, into DBASE III PLUS and have us transfer them into INFO files. This approach worked well; however, gathering the information for entry took more effort than expected. Personnel had other demands on their time besides the pilot project. Assigning attributes could not be given to personnel who had not performed the field work because information from

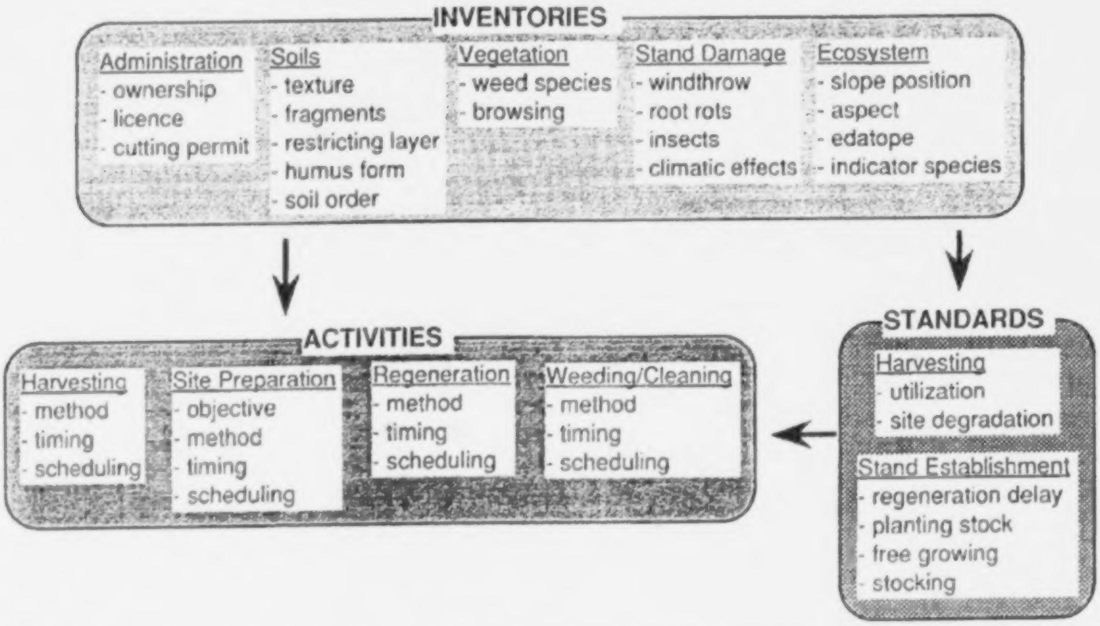

INVENTORIES
Administration
- ownership
- licence
- cutting permit
Soils
- texture
- fragments
- restricting layer
- humus form
- soil order
Vegetation
- weed species
- browsing
Stand Damage
- windthrow
- root rots
- insects
- climatic effects
Ecosystem
- slope position
- aspect
- edatope
- indicator species
ACTIVITIES
Harvesting
- method
- timing
- scheduling
Site Preparation
- objective
- method
- timing
- scheduling
Regeneration
- method
- timing
- scheduling
Weeding/Cleaning
- method
- timing
- scheduling
STANDARDS
Harvesting
- utilization
- site degradation
Stand Establishment
- regeneration delay
- planting stock
- free growing
- stocking

Figure 4. The linkages between coverage catagories (shaded), coverages (underlined) and their thematic attributes in developing a pre-harvest silvicultural prescription.

several sources, including personal recollection, was required. As a result, the pilot project data loading was slowed down and the number of files with thematic attribute data was limited.

Previous tenures for areas also led to problems. Because of the nature of volume-based tenures and chart areas, boundaries defining areas of responsibility are dynamic. As a result, there is not always complete information available for an area.

GIS Interface

With the database and data loading complete, it was necessary to give forestry personnel easy access to the GIS applications and their data. With loading data, a database structure had to be defined first, and with building applications, an interface design was required first. This interface, or unifying application structure, was needed to define:

(i) an environment to build applications in,
(ii) the appearance of applications to the operator,
(iii) how operators could take control of GIS.

A menu-driven interface, written in the ARC macro language (AML), was chosen after reviewing potential operator demands, personal experiences with interfaces and the abilities of AML. The interface was Macintosh-like, following **Human Interface Guidelines: The Apple Desktop Interface**, (Apple, 1987). This adoption was restricted by the architecture of ARC/INFO and the VAX computer.

The final interface uses AML pulldown menus as the centre of control. Choosing from the menu results in immediate action or the display of an AML matrix or form menu, used as a dialogue box (Figure 5). All menu items ending in an ellipsis ("...") lead to a dialogue box and every dialogue box can be canceled without adverse consequences.

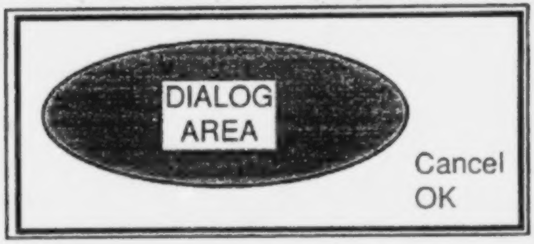


Figure 5. An example of a dialog box. The operator gives and receives information from the dialog area.

At startup, a dialogue box prompts for the operator's name. This defines librarian access, what preferences are used for menu selections and coordinate entry, and who was responsible for any changes to thematic attribute files. This last point will become useful when updating procedures are introduced. The pulldown menus then appear, and the entire administrative coverage is displayed to orient the operator.

The display screen is divided into three areas, forming the appearance of a standard map (Figure 6). The right side of the screen contains the map legend with a map scale bar displayed underneath. Since the initial coverage could potentially be the size of British Columbia, some way of defining the view area or window is needed. By defining opposite corners of the desired window on the screen with the mouse, the operator can window in on a specific area. By using a dialogue box, the operator can window out from an area. When the screen is redrawn, the scale bar is redrawn at the appropriate scale. Display coverages and their display colours are selected from a dialogue box. These coverages can be removed from display in the same way. Once a collection of coverages is displayed, they can be saved as a coverage set to be recalled at a later time.

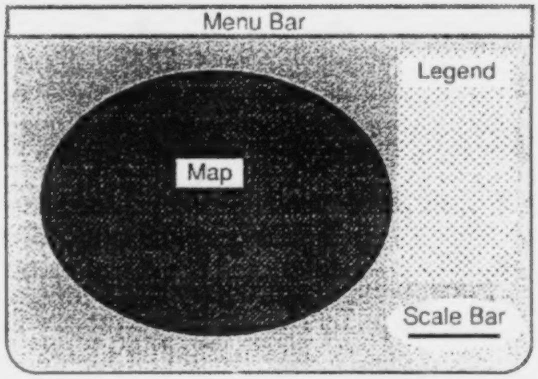


Figure 6. Screen presentation for the forestry GIS.

Applications Development

We define an application as a series of routines which, together with the interface, perform a specific task resulting in the recall and/or creation of information. This information can be tabular or graphic, on a screen or hardcopy. The applications developed for the pilot project were chosen because they were basic to building other applications and because they were required to provide short-term returns for curious and sceptical clients. The two applications chosen provide the ability to:

(i) query the GIS for information, and
(ii) produce standard administrative reports for the provincial government as required by provincial legislation.

Queries

The ability to conduct queries is essential to GIS success. These queries are the means of interactively displaying information from the GIS, and selecting out information for other applications to use. At first glance, designing this application appears simple: regurgitate information from the database and display it to the operator. There are two different ways for the operator to extract information:
(i) selecting specific features and listing their attributes, and
(ii) selecting specific attribute conditions and showing the features having these conditions (Figure 7). For each of these, a separate application is required.

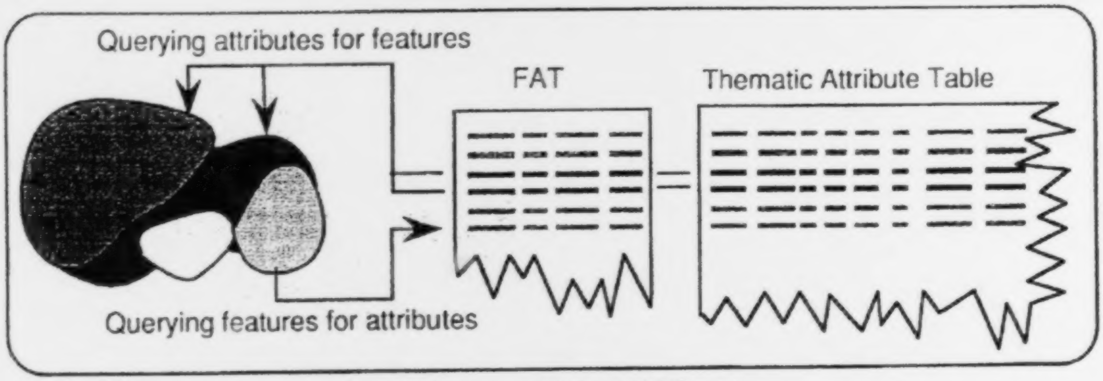
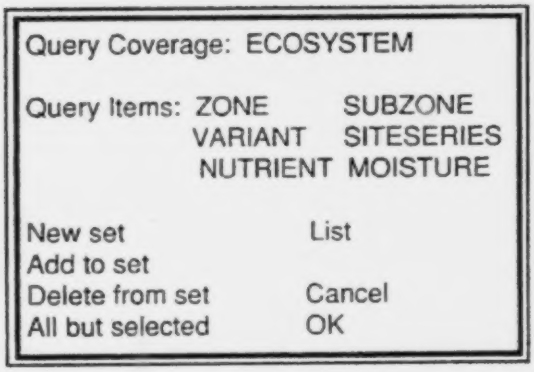

Querying attributes for features
FAT
Thematic Attribute Table
Querying features for attributes

Figure 7. The two possible types of GIS queries.

To query features for their attributes, the features must be selected. This is accomplished using the feature query dialogue box (Figure 8). This dialogue box allows the choice of query coverage and attributes to display to be made. The selected set of features can be started, restarted, added to and deleted from using the query feature dialogue box. Display of attributes for the selected features is performed from within the query feature dialogue box and automatically upon leaving it. The attribute names are listed in the screen legend for future reference.

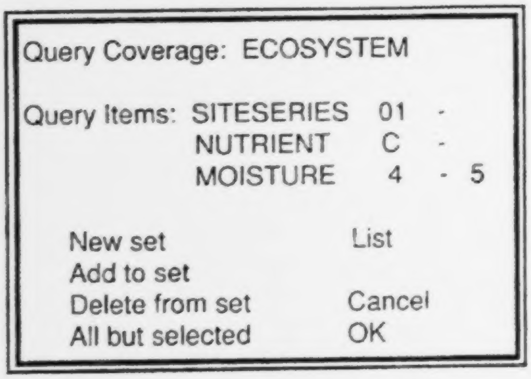

Query Coverage: ECOSYSTEM

Query Items: ZONE SUBZONE
VARIANT SITESERIES
NUTRIENT MOISTURE

Figure 8. The attribute query dialog box.

Querying, based on specific attribute criteria, is more complex. Once the query coverage and the attribute items are selected, the criteria for each attribute must be collected from the operator, using the query attribute dialogue box (Figure 9). Error checking is performed to determine whether the conditions are valid (ie. no letters in numeric attributes). The query then proceeds, assuming that all attribute conditions must be met to select a feature (ie. expression 1 and expression 2 and expression 3 are true). Upon leaving the query attribute dialogue box, or from within the menu, the selected features are displayed, and the criteria used for selection are listed in the legend for future reference.

Through these two types of queries and the options for selecting within each menu, selections can be made based on location and attributes and used for further analysis.


Query Coverage: ECOSYSTEM

Query Items: SITESERIES 01 -
NUTRIENT C -
MOISTURE 4 - 5

Figure 9. The feature query dialog box.

Tabular Reports

An example application to produce a tabular report illustrates the abilities of the GIS to extract attribute information for selected features from the thematic attribute database. The IFS silviculture department, in anticipation of GIS, has developed a pre-harvest silviculture prescription (PHSP) procedure which can be integrated into our GIS. Field cards are designed for direct entry into the GIS. Generating reports is performed by querying for the proposed cut block, and then requesting the PHSP report from the menu. The information for the report is then extracted from the datafiles using spatial referencing, and an external program creates and prints the report. This same approach can be modified for other reports including major licensee silvicultural information system (MLSIS) reports.

Further Development

Development for the coming year is planned to provide more applications for GIS clients, in response to their needs. These include producing large-scale field maps delineating herbicide zones, pesticide use permit requests and field operations scheduling and progress reports for harvesting and silviculture. By spring, we hope to install a digitizing station in our drafting department to begin integrating day-to-day updating and production of mylars into the GIS. As well, we will explore providing the ability to interactively definite ecosystem boundaries and treatment units for harvesting and silviculture.

Closing Remarks

We have learned much by doing, and hope to continue the learning process. GIS is not a simple matter because the forestry community's needs are not simple. Hence, the evolution of a forestry GIS has taken a long time. We think our pilot project has been successful in illustrating what GIS is capable of providing, and determining how much development effort is required.

In continuing to develop practical and realistic implementations of GIS, we all need to closely examine our profession's expectations. Will personnel be able (want) to load and update their own attribute and spatial data? Should we expect to make all of our GIS dreams come true in the near future? If not, where should we concentrate our efforts? Is it reasonable to expect microcomputers to deliver our expectations? As professionals, we need to look carefully at our expectations, our goals and our means to achieve them before being disappointed about GIS. We may have 'the system', and maybe even 'the plan', but until we acknowledge, appreciate and deal with the complexities involved in our dreams, we won't have 'the reality'.

Acknowledgements

IFS wishes to thank Rustad Bros. & Co. Ltd. for their support in our pilot project and in particular, Jack Hays and Paul Sears for their help with loading data and interest in our progress.

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Woods Production Planning and Inventory Control System

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Abstract

A joint research project between MacMillan Bloedel Limited, the Forest Engineering Research Institute of Canada, and the National Research Council has produced a prototype decision support system (DSS) which is targeted towards frontline harvesting supervisors. The objective of the DSS is to aid day-to-day decision-making for the best deployment of personnel and harvesting equipment. The results of different harvesting plans can be assessed via graphics or tabular data, showing felled and bucked inventories by area, production by species, as well as equipment utilization.

Introduction

This paper describes a prototype decision support system developed in a joint research project between the Cameron Division of MacMillan Bloedel Limited (MB), the Forest Engineering Research Institute of Canada (FERIC), and the National Research Council of Canada (NRC).

MacMillan Bloedel's objective was to evaluate new computer-based technology that would assist harvest planners with their day-to-day operational decision-making process. FERIC's objective was to develop new technology for assisting harvest planners with their operational scheduling activities. NRC's objective was to develop computer-based decision support systems technology for solving a general class of "capacitated-flow" problems. NRC expects that the technology and approach used to solve this particular problem, once proven, can be applied to similar problems in other resource industries.

Within the scope of the various research objectives, the following goals were defined for designing the system:

- It must be usable by a decision-maker who may not be computer-literate. The audience for the software is woods foremen or logging superintendents,
- It must support a natural decision-making process i.e. the software should mimic the processes involved in making typical decisions in real-life situations,
- It should allow a decision procedure that is interactive and modifiable. There should be immediate feedback when a decision is made and it should be easy to alter any decision,
- It should convey its information with visual representations without resorting to a myriad of numbers. The visual representations should incorporate shape, size, colour, and pattern,
- It must provide essential information without demanding excessive input; the information produced by the system should be more useful than the information input,
- It should combine the real intelligence of the human decision-maker with the information-handling capability of the computer.

Several alternative topics from the harvesting sector that would embody these goals were examined before a topic was selected for the prototype software. A woods production planning and inventory control system satisfied the research objectives for all the project participants and it was felt that it was feasible to complete the prototype within the time and resource constraints of the project.

Inventory planning is done approximately once each month, and this was an important consideration in selecting the project topic. This level of activity would allow proper field-tests of the software to be carried out within a reasonable period of time, yet it would not place unrealistic demands on the prototype program.

The software was modelled on a manual system that MB uses to manage their felled and bucked timber inventory. In the manual system, divisional personnel update actual equipment locations monthly and then recalculate the felled and bucked timber inventory volumes. Next, they predict the equipment moves to be made over the coming four-month planning period to satisfy the log flow requirements by species and grade from the logging division. The current system is based on manual calculations and information retrieval; the only computer technology employed is a digitizing program to calculate map areas.

The current manual system requires approximately three man-days to complete the map updates and calculations required for the reports, making it impractical to evaluate more than one alternative. The resulting plans are often obsolete before implementation because of variability in terrain, weather, and other conditions in the logging areas; thus, the plans and their implementation are likely to be less than optimal. MB recognized that improved and more timely equipment deployment decisions could result from software developed in the project.

From a technical point of view, NRC recognized that the boundaries of the inventory control system were well-defined, and that the project could be carried out as an independent project. It did not depend on any other software development and, if the project was successful, MB would continue to benefit from its use.

The software was developed by NRC using a step-by-step approach with continual referral to MB and FERIC for criticism. The authors acknowledge the valuable contributions to the project from Frank Hillier, Tony Timberlake, and Doug Richmond of MB Cameron Division and Hiroshi Tamoto of the NRC Systems Laboratory in Vancouver.

SYSTEM DESCRIPTION

Unique Features of the Software

The prototype software has several unique features which make it appropriate for use by the target audience.

The system is interactive and mimics the real-life decision-making process, e.g., the logging assignments are made by selecting equipment "icons" and placing them upon the desired logging sites. Logging methods and production rates are selected by making choices from a menu.

The system is visual in that it presents pertinent information by using shapes, sizes, colours, and patterns; it can also provide quantitative as well as pictorial information. Time-based information is also presented visually via appropriate bar charts, Gantt charts, and multi-line graphs. The same colours and patterns are used throughout the system to provide consistency in data presentation.

The system allows the operator to record all decisions in a "script" and then play the script like a video tape. The decision-maker may commence the playback from any date within the planning horizon, and may proceed in forward or reverse motion. The decision-maker may take over at any

time to alter the script, then record the modified script for subsequent playback and further modification.
The system is designed to be used directly by the decision-maker rather than by an intermediary. Furthermore, it does not usurp his expertise and authority, thus it is referred to as a "decision-support" system rather than a "decision-making" system. The user and system work as a team in a symbiotic manner, each contributing to the decision-making process. This type of approach takes full advantage of the real intelligence of the human being and the artificial intelligence of the computer.

The prototype system, which combines all these features, is referred to as a "visually interactive decision support system".

Implementation
"Resource" is used to indicate entities that the decision-maker has available for deployment; a resource changes the inventory from one state to another. A resource can be labour, equipment, contractors, etc., that must be deployed in the plan. For the Cameron Division, the resources were falling crews, yarders, and loaders.

The planning process for woods inventory control consists of seven steps which essentially remain the same whether the decision-maker uses a manual or computer-assisted system. The seven steps are:

- Define the logging sites,
- Define the resources,
- Develop a logging plan by assigning resources to the logging-sites and assigning them logging tasks,
- Evaluate the logging plan by assessing the resulting inventories, equipment utilization, production, etc,
- Playback and modify the logging plan either by deploying the resources to alternative sites or by changing their logging tasks,
- Implement the logging plan,
- Monitor the progress of logging activity by comparing actual results with projected, and revise the logging plan whenever necessary.

The software developed for this project allows the decision-maker to carry out these steps. Sites and resources are defined with site and resource editors, then the software simulates the resource activity on a day-by-day basis to determine the results of resource-deployment decisions. Analysis tools such as gantt and line charts are used to evaluate the plan's effectiveness. The plan can be played back and reviewed through the provisions of a script recorder.

A calendar can be "attached" to a logging site, a resource, or the whole division allowing the decision-maker to specify working days, non-working days, holidays, and maintenance days. Production is recorded for a resource only when the calendar confirms the work day for the resource, the current logging site, and the whole division.
The implementation of these steps within the prototype software is as follows:

Step 1 - Define the Logging Sites.
Each site is represented by an icon which shows a bar chart depicting the current timber volumes for the various logging methods used on the site. These bar charts are updated dynamically during the planning process to provide the decision-maker with constant graphical reference to the current status of the site. Figure 1 shows icons for two sites in Cameron Division (Cor_150-4 and Cor_100-4) and icons for the various equipment resources. New logging sites can be created at will.

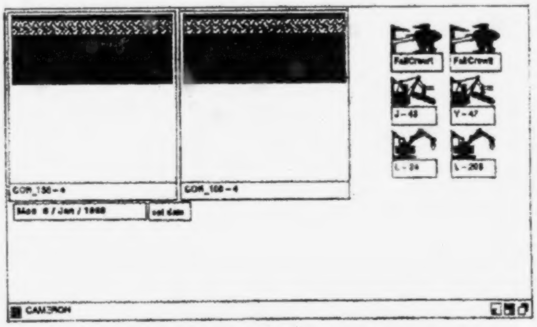
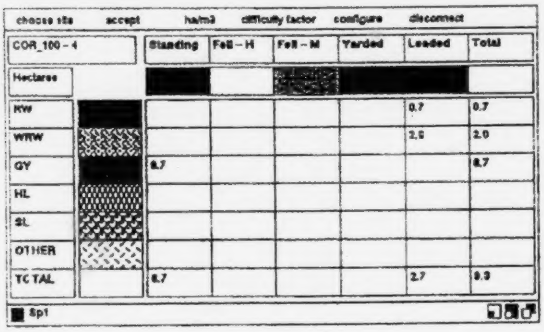


Figure 1. Icons for logging sites.

The numerical data for each site can be viewed by using the mouse to attach a site editor to the site. The site editor (Figure 2) is a generalized spreadsheet which uses the columns to represent the possible states of the site, and the rows to represent the various logging methods. The decision-maker is able to customize the site editor by defining as many columns (states) and rows (logging methods) as required, and selecting his own colours and patterns for display.

For Cameron Division, for example, the possible states for timber are standing, hand felled, mechanically felled, yarded, and loaded, while the possible logging methods are right-of-way, wide right-of-way, grapple yarding, high-lead, shovel logging, and other. Notice that the patterns used for the various logging methods match the patterns shown on the bar chart icon in Figure 1; it can be seen by pattern alone that Site Cor_150-4 is comprised of RW, WRW, and GY timber. Through the use of colour, the bar chart also provides information regarding the inventory's current status.

To define a site, the decision-maker simply enters the current volume or hectares of timber in the appropriate cell on the spreadsheet. As values are recorded or modified, the column and row totals are automatically updated and the bar chart associated with the site updates itself to display the same information, but graphically. The pattern of a bar



COR_100 - 4		Standing	Fell – H	Fell – M	Yarded	Loaded	Total
Hectares		■		▨	■	■	
RW	■					0.7	0.7
WRW	▨					2.0	2.0
GY	■	8.7					8.7
HL	▨						
SL	▨						
OTHER	▨						
TOTAL		8.7				2.7	9.3

Figure 2. Site editor spreadsheet.

represents the logging method (e.g. RW), and its height indicates relative volume. Similarly, the colour of the bar represents its current status (e.g. standing), with its width indicating relative volume.

Each site also has a rudimentary map associated with it that displays the same status and logging method information as the site icon and the spreadsheet. The maps for the prototype (Figure 3) were constructed using a mouse, although future enhancements could derive this information directly from a geographical information system.

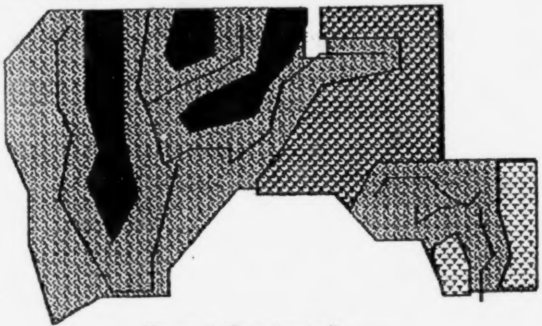
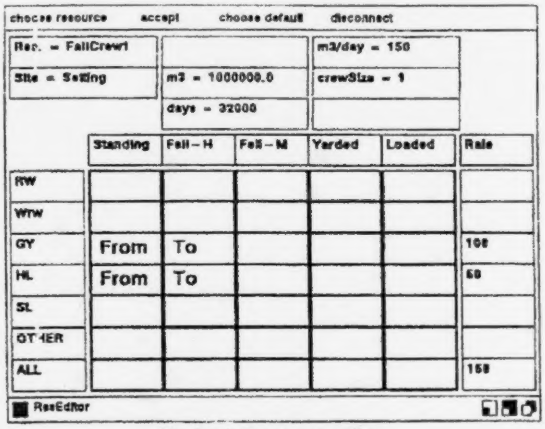


Figure 3. Prototype site map.

Step 2 - Define the Resources.
In a manner similar that used to define sites, the decision-maker creates and sets up all the resources by using a resource editor (Figure 4). Just as with the site editor, the resource editor is attached to the desired resource by pointing with the mouse. The beginning and ending states for the inventory are specified (e.g., fallers commence with standing inventory and finish with felled inventory) for the resource by using the mouse to make selections. This scheme allows for very flexible resource definitions (e.g., full-phase logging contractors commence with standing inventory and end with hauled inventory). The resource icon can be easily altered to represent a new type of equipment.

Each resource has a default production rate that is entered via the resource editor. Also, one resource icon can represent more that one physical item; for example, each falling crew can consist of several individual fallers.



Res. = FallCrew1				m3/day = 150		
Site = Setting		m3 = 1000000.0		crewSize = 1		
		days = 32000				

	Standing	Fell – H	Fell – M	Yarded	Loaded	Rate
RW						
WRW						
GY	From	To				100
HL	From	To				50
SL						
OTHER						
ALL						150

Figure 4. Resource editor.

Step 3 - Develop a Logging Plan.
The software mimics the real-life processes required to develop a logging plan; for example, a loader may be sent to a specific logging site and instructed to load logs from the right-of-way at 350 cubic metres per day for three days. To create a corresponding logging plan with the software, the decision-maker selects and moves an icon of the loader onto the icon of the desired logging-site with the mouse. He then designates the specific logging task (i.e. load logs from the right-of-way at 350 cubic metres per day for three days).

The decision-maker determines all the other assignments required for the day, then starts the calculation process. The system instructs every resource on every logging site to do one day of work, then calculates the resulting status of the logging site and presents this information graphically by updating each site's bar chart. It then determines if any resource requires a change of assignment as a result of completing its current task. If not, the system continues the process of simulating each day's activities until a resource requires attention, at which point the resource is highlighted with a red flag. The simulation is halted to allow the decision-maker to make further assignment decisions.

This sequence of making decisions and simulating the logging operations continues until all sites in the plan are completed or the decision-maker wishes to stop.

The resulting logging plan, including all decisions and the daily status of each site and each resource, is saved as a script which the decision-maker may refer to at a later time for review and modifications.

Step 4 - Evaluate the Logging Plan.
The resulting timber inventories in the various states, the equipment utilization, and timber production by species and grade are calculated in order to evaluate the plan. The system presents this information with a generalized chart

which may be attached to any logging site to examine, for example, the history of the woods inventory (Figure 5). The X-axis of the chart displays the passage of time and the Y-axis displays felled and bucked, yarded, and loaded inventories. The same chart can be attached to the logging division instead of a logging site, to display the information accumulated for all logging sites in the division.

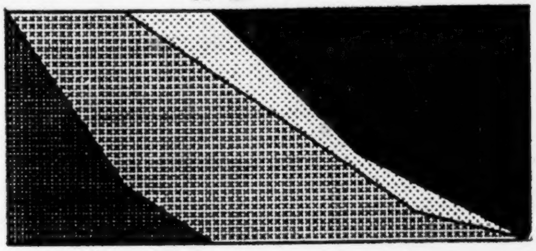


Figure 5. Timber inventories over time.

Similarly, the daily production by species and grade, equipment utilization, and productivity statistics can be displayed. The same colours as those used in the site and resource editors are used to highlight the relevant information (e.g., standing inventory is shown as green, yarded inventory as yellow, etc.).

Step 5 - Playback and Modify the Logging Plan.
Once a logging plan is developed the decision-maker may choose to play it back or review it (as can be done with a video tape) by selecting a previously recorded script and by choosing a starting date for playback. Beginning with the selected starting date, the system displays the current status of each logging site and duplicates all the succeeding resource deployments recorded in the script. At any point during the playback the decision-maker may stop the system and take control manually to change the previous decisions and try alternative plans. The resulting logging plan may be saved as a separate script which can be played back and further modified. This process continues until the decision-maker is satisfied with the logging plan.

The playback feature may be invoked in forward or reverse motion, thus allowing the decision-maker to roll back to a previous decision and change it without having to start over again.

Step 6 - Implement the Logging Plan.
A completed logging plan may be implemented by printing the plan, in chronological order, either from the viewpoint of logging site, in which case it may be handed over to an area supervisor for implementation, or by resource, in which case it may be handed over to the appropriate crew to show the crew members their assignments. The printed plan shows the logging tasks for each resource on each logging site as illustrated in Figure 6.

Step 7 - Monitor the Logging.
This is an on-going daily activity where operations staff may choose to compare their actual experience against the projected results. If they detect significant differences at any point, they may then choose to evaluate alternatives and implement a revised plan.

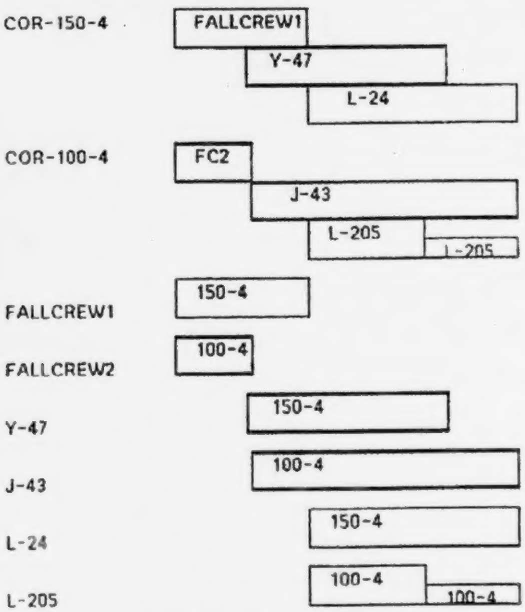


Figure 6. Logging plan by site and by resource.

In this manner ,the planning process becomes a perpetual activity driven on an exception basis (i.e., modify a plan only when it is necessary or 'management by exception') as opposed to a calendar-driven activity (i.e. develop a plan at each month-end or 'management by rule').

DISCUSSION

This system is adaptable and extendable to other applications within and without the forest industry. In fact, it may be used for developing schedules for any finite-state process (e.g. silviculture considerations, contractor scheduling, mining operations, etc.). Furthermore, the system may be extended to produce annual operating plans, five-year forest resource plans, and even 20-year to crop-rotation cycle plans. The system has the capability to address cutblocks or logging sites, operating areas, watersheds, or entire forest management licenses. As well, access to growth and yield models, fire and protection models, silviculture and wood supply models could be provided from within the system. Finally, it is possible to incorporate the results of equipment productivity studies (such as those done by FERIC) and company-specific cost data to assess the economic impact of alternative decisions.

Further Application Opportunities.
This prototype software was developed to support the decision-maker, and can provide a positive payback on investment if brought to the decision maker in an easy-to-use environment. However, visually interactive decision support systems have benefit beyond the immediate decision-support role.

A visually interactive decision support system can help the user to understand the sensitivity of decisions to inaccuracies in data. Not all data can be assumed to have the degree of accuracy required or desired by decision-makers. The system may be used to understand and evaluate the effect of inaccuracies in input data and to identify those areas where improved accuracy would have a significant payback, thus justifying the cost of getting higher accuracy. For example, more accurate cruise inventory information may provide more accurate decision-making during harvesting.

The system can also be used for training new decision-makers and honing decision-making skills. Visually interactive simulation models may be used in the same fashion as flight simulators are used by the airline industry. This technology allows a decision-maker to 'test fly' innovative alternatives which it may not be feasible to try in real life.

The software can also provide an excellent way of disseminating information and communicating with others both inside and outside the organization (e.g., meetings, public hearings, etc.). In today's society where public participation and debate over issues is becoming common, this last use may reap significant benefits.

Current Project Status.
The project software was developed in a new object-oriented programming environment called AUDITION, which is still under development and is not yet available on the market. One of AUDITION's most beneficial features is that it allows program parts to be independently developed and tested; this feature has allowed development and testing of the system components without having the whole system functional. At present, not all system components have been amalgamated in the computer at one time because of the DOS 640-kB memory barrier, although a solution to this memory limitation is expected in the near future. At that time, the components will be brought together into a working prototype for the field trials.

Approximately one month after the initial field tests at Cameron Division, further field testing at a second site in Alberta is scheduled, using a longer planning horizon and different resources and logging methods. This second trial will also accommodate both harvesting and silviculture states of the forest land. Technical development is also being considered to explore the possibilities of linking the software to a geographical information system, a relational database, and external modelling programs.

The same object-oriented AUDITION software technology, coupled with the experience gained through this project, has been instrumental in the development of a conceptual framework for FORest Engineering, Management, Operations and Silviculture Technology (FOREMOST). This is a concept for integrating the long, medium, and short-term planning and scheduling needs within a single intuitive and interactive computer system. The inventory control prototype software will form just a small part of FOREMOST, but the visual representations and the operating environment that were explored and proven in this project will be central to its design.

CONCLUSIONS

Pending results of the field tests, the project objectives have been achieved because a visually interactive scheduling system that can be easily used by non-computer-literate supervisors for their day-to-day planning decisions has been developed. The software is intuitive and interactive because of its use of visual indicators such as size, shape, colour, and pattern to convey information, as well as the use of icons of real-world objects for resources and sites.

Furthermore, the project objectives have been exceeded; the goal was to develop software for managing felled and bucked timber inventory and, instead, a generalized finite-state scheduling system has been developed. With minimal effort, the screens and icons can be adapted to conform to the requirements of many scheduling problems.

Managing Resource Conflict

Session A2
DEMs: Visibility Analysis

Assessing the Visual Impact of Development Plans

Automation of Visible Area Mapping for Fire Detection Lookouts

GIS and Computer Video-imaging in Forest Landscape Management

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Assessing the Visual Impact of Development Plans

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Abstract

In today's society, everyone is being encouraged to be more sensitive to the environmental repercussions of their day-to-day activities. This sensitivity is amplified in those cases where visual impact is most evident. The forestry industry is continually being encouraged to engage in more aesthetically pleasing logging practices.

Coast Wood Products Division of Fletcher Challenge Canada Ltd. recognised that its CARIS system had the potential to address this ever-increasing need and to provide a useful tool in addressing the visual impact of its development plans.

Working with Universal Systems, existing CARIS software for Digital Terrain Modelling was enhanced to meet forestry industry needs. The module includes not only the ability to view surfaces in 3D, but also to depict the cleared areas and forest cover over time. Height and crown closure are included as parameters in generating the display. This enables the determination of whether or not an area of interest will be visible from a specified location and how the harvesting and regeneration will appear over time. This in turn provides for a more accurate portrayal of the visual impact of the proposed development plan.

This paper outlines the process of defining these special needs and the evolution of the software development towards its present use as a practical planning tool at Fletcher Challenge Canada Ltd.

1. Introduction

Environmental concerns are becoming increasingly important in the British Columbia forestry industry. While people once accepted that problems such as erosion and landscape disfigurement were simply the price that had to be paid for an economic forestry industry, attitudes have changed in favour of active environmental protection, especially in the last few years.

This sensitivity is amplified in situations where the visual impact of forest development is most evident. In these cases, the forestry industry is continually being encouraged to engage in more aesthetically pleasing logging practices.

Forestry companies have long been required to prepare 'Five Year Development Plans', in order to show proposed harvesting areas. It has only been in the past few years, in some high visibility areas, that 'viewshed analysis', showing which parts of logged areas are noticeable, has become an important part of these plans.

As part of the visual material that accompanies forest development plans, artist's impressions have been used. An artist combines pre-harvesting photos of the area, pictures of similar areas after logging and development plans, to produce a visualisation of the resulting landscape. These pictures have, however, been difficult to produce accurately; and decisions based on misleading visualisations can literally take a lifetime to be corrected.

The Coast Wood Products division of Fletcher Challenge Canada Ltd recognised that it could improve its viewshed assessment by making use of GIS technology. Fletcher Challenge had acquired a CARIS GIS system from Universal Systems Ltd (USL) of Fredericton, NB, Canada, in order to keep track of its forest inventory and for project planning. The CARIS system's Digital Terrain Model (DTM) module was enhanced to provide accurate and realistic landscape simulations, allowing the assessment of proposed logging developments' visual impacts.

This paper first introduces the CARIS DTM module, and outlines the technical specification of the project. Next, the way in which visualisations are produced using the DTM module is described and several methods which are used to improve the visual realism of the simulation are discussed. The software has been used in the Sulphur Pass area of Vancouver Island; this case study is described in detail. The concluding remarks include some notes on further work which can be done in this field.

2. The CARIS DTM Module.

Digital Terrain Models (DTMs) in CARIS use a network of plane triangular *facets* to define a surface (Figure 1). The data is organised as a Triangulated Irregular Network (TIN) [Peucker et al, 1977]. The 3D coordinates of the vertices are stored in a digital file, along with information defining the vertices which relate to each facet. Auxiliary attribute information can be stored; for example, the terrain type represented by a surface facet can be represented by a character key, such as 'SEA', or 'FOREST', optionally stored with each facet. Geometric attributes, such as slope, aspect or height are computed when needed.

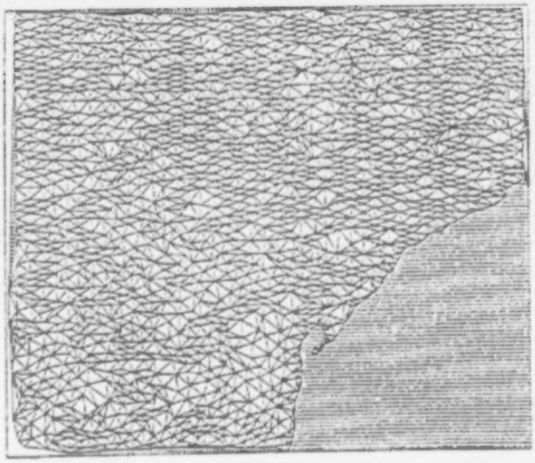


Figure 1. a terrain surface represented as a DTM

The DTM module can be used for applications such as:

- automatic contour generation,
- slope and aspect mapping,
- interpolation of 3D digital vector data without expensive resurveying,
- flood risk zone delineation,
- design of dredging zones, and subsequent dredging volume calculations.

The DTM module also contains a 3D visualisation function, *V3D*, in which DTMs can be drawn on a graphics screen, with hidden surface removal and with surface colouring according to some user-specified classification scheme. Map features, such as roads, contours, names and symbols can then be draped over this surface and can be seen in 3D. A number of DTM and map editing functions are also provided within V3D.

3. The Visualisation Project Requirements

The visualisation project involved a series of enhancements to the CARIS DTM module. The first step was to allow perspective projection. Up to this stage, only an orthogonal (constant scale) projection could be employed, whereas the perspective projection, where scale decreases with distance from the viewpoint, offers a more realistic view.

A second requirement was the ability to view from a ground position within the DTM: previously, the viewpoint always had to be from outside the DTM area. Viewing from within the DTM is essential if a simulation is to show how the landscape looks from a particular viewpoint on the ground.

The third requirement was for a user to be able to *zoom* in and out of the picture, simulating a camera's zoom lens. Up to this stage, zoom was possible only if the graphics device had a local zoom capability.

The final enhancement was to find some representation for forested areas, so that they could easily be distinguished from clear-cuts.

4. The Viewing Algorithms

Perspective projection was achieved using well-known formulations [Newman & Sproull, 1979]. Allowing a view from within the DTM also involved the clipping of facets where they pass outside the viewing pyramid (an imaginary pyramid, with its apex at the viewpoint, within which visible objects lie). Hidden surface removal is done using the 'painter's algorithm' [Newman & Sproull, 1979], in which facets are sorted according to their distance from the viewpoint, and are displayed from farthest to closest.

5. Added Realism

Visual realism in the simulated landscape is added by the use of colour, hill shading, symbolization, and by adding colour fill for sky and foreground.

5.1 Colour

DTMs can be coloured according to values associated with its facets. Each facet is classified according to one of the following criteria: slope (steepness), aspect (the direction in which the normal to the facet points), height, or by a character key. Class intervals are associated with colours, and facets are coloured according to the interval into which they fall. For example, slopes might be coloured according to the following scheme:

Slope	*Class*	*Base Colour*
0.0 to 1.9	1	light blue
2.0 to 4.9	2	medium green
5.0 to 9.9	3	pale green
10.0 to 19.9	4	pale brown
20.0 to 29.9	5	medium brown
30.0 to 90.0	6	red

In the case of landscape visualisation, facets are typically coloured according to their character keys. A key, such as 'SEA' or 'PLANTED1973' can optionally be stored with each facet of the DTM. A definitions table, similar to the one above is used to assign a colour to each facet on drawing.

Keys are assigned to the facets by overlaying the DTM with a polygon file. The polygon file defines the areas which are forested, the areas which are to be logged, and other areas, such as sea or lakes.

5.2 Hill Shading

As well as colour, hill shading is used to give a more pronounced 3D effect to the view. The shading simulates the effect of the sun on the terrain - slopes facing toward the sun are lighter than slopes which face away. This effect is achieved by drawing the facet with a greater or lesser lightness of the facet's base colour. A list of 20 different tints of each colour is kept. The appropriate tint is computed using the dot product of the sun's vector and the normal vector to the facet (Figure 2).

In the viewing system, the light source's position can be selected so that it 'shines' on the DTM from any chosen direction. This is useful in views from above the DTM, since in this case the most realistic 3D effect is obtained with hill-shading using a light source at the top-left corner of the image. By selecting a position for the sun, this effect can be achieved, regardless of the viewing orientation.

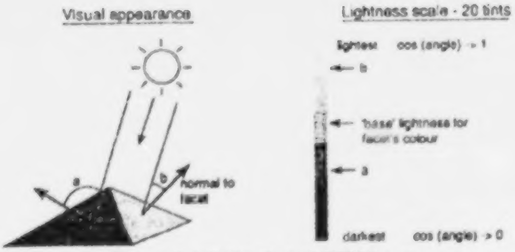

Visual appearance
a
b
normal to facet
Lightness scale - 20 tints
lightest cos (angle) -> 1
b
'base' lightness for facet's colour
a
darkest cos (angle) -> 0

Figure 2. hill shading of DTM facets

5.3 Tree Symbols

Tree symbols are particularly effective in improving the visual realism of the simulation. Often, logged areas which are visible before trees are drawn will become invisible once tree symbols are added; the occluding effect of trees is especially noticeable in gently sloping landscapes. Thus, it is important that a visualisation capability allows realistic tree symbolisation.

V3D includes tree drawing as an option. The user is able to specify the following characteristics:

- the character key for facets which are to have tree symbols (eg, 'FOREST'),
- the tree height, in ground units such as metres,
- the average spacing between trees, in ground units,
- whether a tree canopy is to be drawn, and its radius,
- the base colour for the tree canopy.

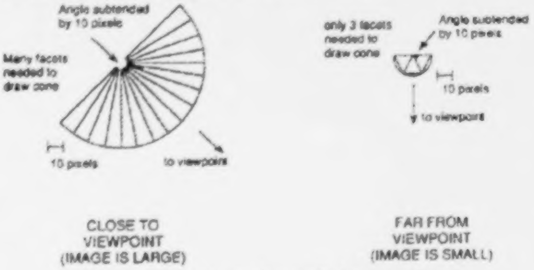
The tree symbols are defined in the ground coordinate system, using the user-definitions above. They pass through the same projection and viewing pipeline as the DTM, so that each tree symbol is accurately represented on the image.

Trees are positioned using a regular grid, with the grid spacing defined by the user. If the facet being drawn has the correct character key, then any grid intersection on the facet will have a tree symbol drawn on it. To avoid an overly regular effect, a small random shift is applied to the ground position of the tree before drawing.

The tree canopy approximates a cone using plane triangular facets. Since many facets are used, with only a small difference in aspect between adjacent facets, the impression of a perfect cone is given. The use of triangular facets also has the advantage that aspect shading, using the same algorithm as the DTM hill shading, can be applied to each facet. This emphasises the realism of tree symbols and enhances the 3D effect.

Drawing many facets for each tree can considerably increase the time taken to draw the image, and has a significant impact on the memory requirements of graphics terminals, if a display list is kept. Therefore, as few facets as are needed to represent each tree are drawn. When the tree is far from the viewpoint, and is consequently projected to a very small symbol, only a few facets are needed. When a tree is very close, many facets must be drawn to maintain the impression of a cone.

The number of facets to be drawn is decided as follows. The tree's position (at the base of the trunk) is projected into 2D screen coordinates (a coordinate system measured in pixels). A point with the same Y ordinate, and 10 pixels distant in X is back-transformed to ground units. This allows the ground distance which represents 10 pixels at the projected tree position, to be found. This distance, and the tree radius (user-specified) are used to compute the angle, measured at the tree centre, which is subtended by 10 pixels on the screen. Canopy facets are now computed and drawn, with the facet width defined by the increment angle just computed. Figure 3 shows the concept.


Angle subtended by 10 pixels
Many facets needed to draw cone
10 pixels
to viewpoint
only 3 facets needed to draw cone
Angle subtended by 10 pixels
10 pixels
to viewpoint

CLOSE TO VIEWPOINT (IMAGE IS LARGE)

FAR FROM VIEWPOINT (IMAGE IS SMALL)

Figure 3. method used to optimise tree drawing

Using this method, trees far from the viewpoint may have only one or two facets, while trees close by can have up to 360, since each facet is made to subtend at least one degree. This reduces the time and memory constraints of tree drawing.

5.4 Sky and Foreground Colour

A fourth improvement in visual realism is to draw the sky and foreground colour. This involves computing the horizon's position on the screen. The horizon drawn is the 'sensible' horizon, as defined in [Bowditch, 1984]. Although it would be more correct, to use the 'visible' horizon [Bowditch, 1984], the difference between the two is insignificant over the small areas involved in landscape visualisation.

The sensible horizon is simply defined by the horizontal plane passing through the viewpoint. The Y ordinate for a point on this plane is calculated, and this Y ordinate defines the position of a horizontal line on the screen, dividing earth and sky. The two zones' colouring is defined by the user.

6. Case Study: Sulphur Pass, Vancouver Island, BC.

The DTM software was applied to a proposed development at Sulphur Pass, an inlet on the west coast of Vancouver Island. The area is shown in Figure 4, using V3D, with an orthogonal projection. Figure 5 shows the area using perspective projection.

Many of the communities in the Sulphur Pass area have traditionally relied on fishing for their livelihood. In the past decade, however, tourism has become increasingly important as pleasure craft owners have come from across North America to view and explore the diverse British Columbia waters. Residents are increasingly anxious about the effects that adverse environmental impacts could have on this new industry. Thus it has been very difficult to obtain approval of forest development plans.

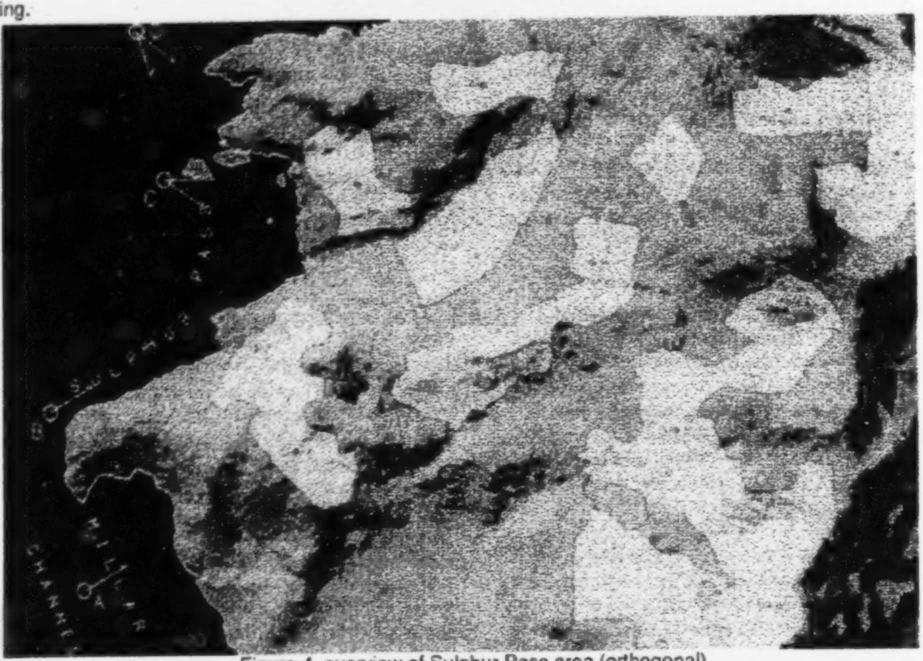


Figure 4. overview of Sulphur Pass area (orthogonal)

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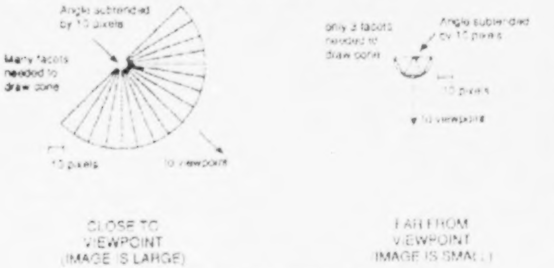
Angle subtended by 10 pixels
Many facets needed to draw cone
10 pixels
to viewpoint
only 3 facets needed to draw cone
Angle subtended by 10 pixels
10 pixels
to viewpoint
CLOSE TO VIEWPOINT (IMAGE IS LARGE)
FAR FROM VIEWPOINT (IMAGE IS SMALL)

Figure 3. method used to optimise tree drawing

Using this method, trees far from the viewpoint may have only one or two facets, while trees close by can have up to 360, since each facet is made to subtend at least one degree. This reduces the time and memory constraints of tree drawing.

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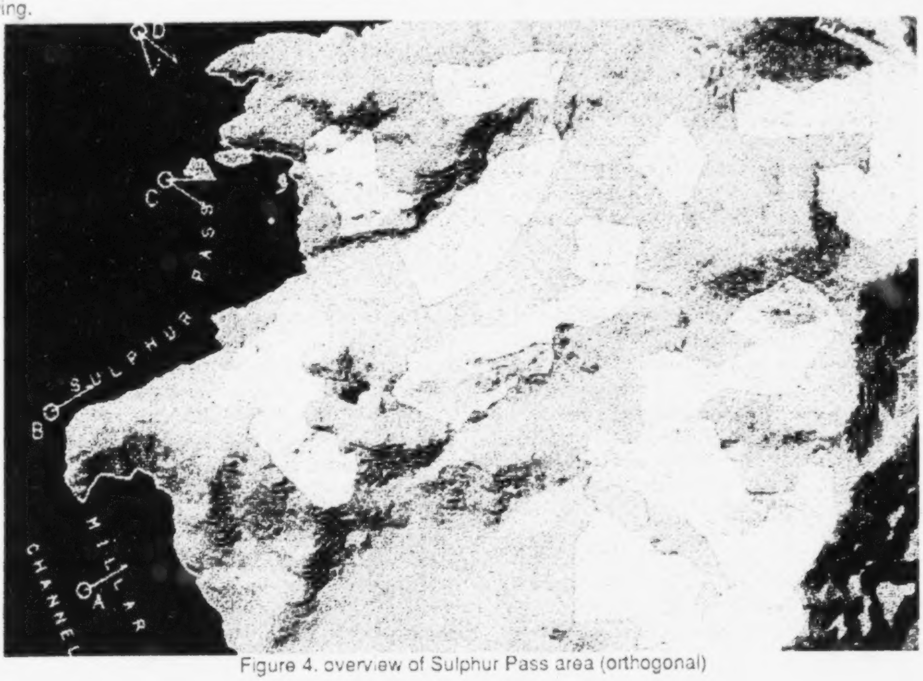

Figure 4. overview of Sulphur Pass area (orthogonal)

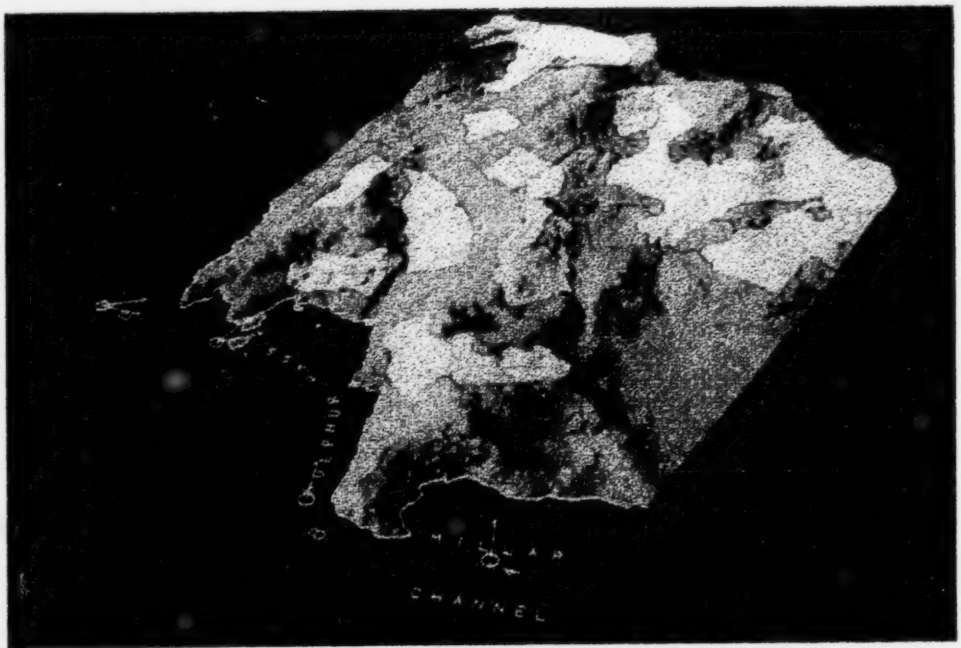

Figure 5. overview of Sulphur Pass area (perspective)

6.1 Preparation of the DTM

The preparation of the DTM for visualisation involved a series of steps, carried out as a number of CARIS commands; these steps are described briefly here:

1. *Create a DTM:* a contour map of the area was digitized and these contours, at a 20m vertical interval, provided the points for the DTM. Also digitized for the DTM were coastlines, islands and lakes. Polygons, defining areas to be logged, were digitized at this stage, though only in 2D (with no height value). The polygon vertices were therefore excluded from the DTM at this point.
2. *Convert the polygons to 3D:* the polygons, defining the edges of the logged areas, were then given height values, using the DTM as a basis for interpolation. This step is needed so that the polygon vertices can be included in a new DTM as breaklines (lines defining a break of slope). In the new DTM, no facets cross the polygons; otherwise the polygon edges would appear ragged during visualisation.
3. *Make a new DTM, incorporating polygons:* the new DTM includes the polygon vertices, since they have now been assigned heights.
4. *Assign character keys to the facets:* the new DTM now receives character keys, (in this case, of 'SEA', 'LAKE', 'FOREST' and 'LOGGED'). This step involves a CARIS function to overlay the polygon map onto the DTM. Each of the polygons has a character key and each DTM facet receives the key of the polygon in which the facet's centroid lies.

The preparation procedure is described in detail in the CARIS DTM User's Guide.

6.2 The Landscape Visualised

With the DTM prepared, the model could now be viewed from the specified ground positions A, B, C and D (the points are identified in Figures 4 and 5). The viewing height was 3m above sea level. The views are shown in Figures 6 to 11.

The images were created in perspective projection, with a 'focal length' of 50mm, and a 'film format' of 35mm, so that the image is close to that seen by the human eye. Figure 12 is a 'zoomed-in' version of Figure 8, using a 'focal length' of 100mm.

6.3 Assessment of the Results

The images produced appear quite realistic, particularly when the tree symbols are added. The location and extent of visible areas became much more apparent after using the DTM module.

Certain areas were particularly obvious in the images. For example, viewed from the north, polygon 0-2, (see Figures 8 and 11) on the south shore of the Sulphur Pass is almost totally visible, due to its steepness and the lack of foreground obstruction. Other areas, such as polygons 0-5 and 0-3, viewed from point C, (see Figure 8) are almost totally hidden in a valley behind an intervening hill. Some areas are very successful; for example, polygon S-5-A, viewed from point A (see Figure 6), is invisible due to surrounding hills.

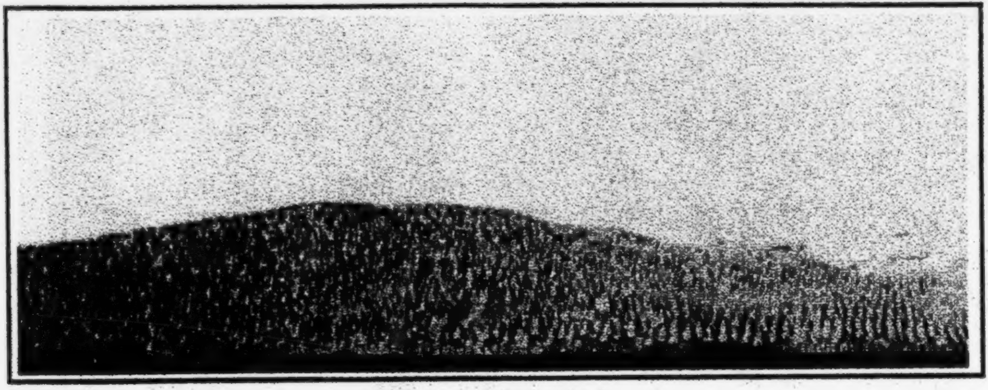

Figure 6. view from point A

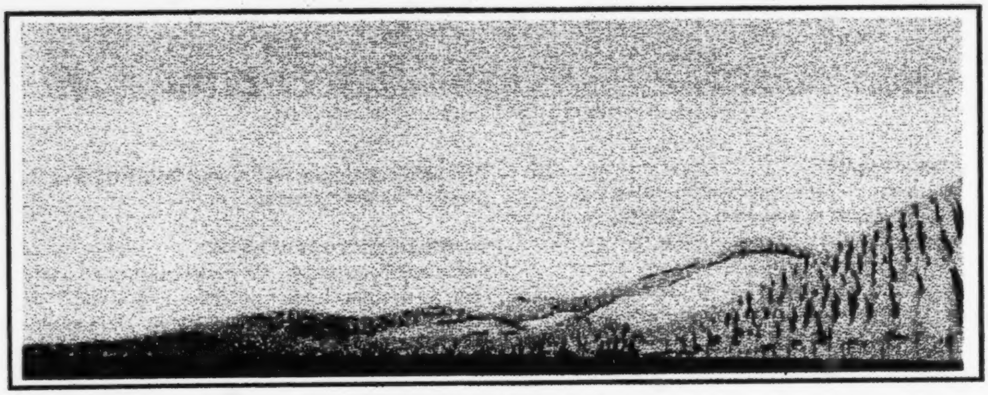

Figure 7. view from point B

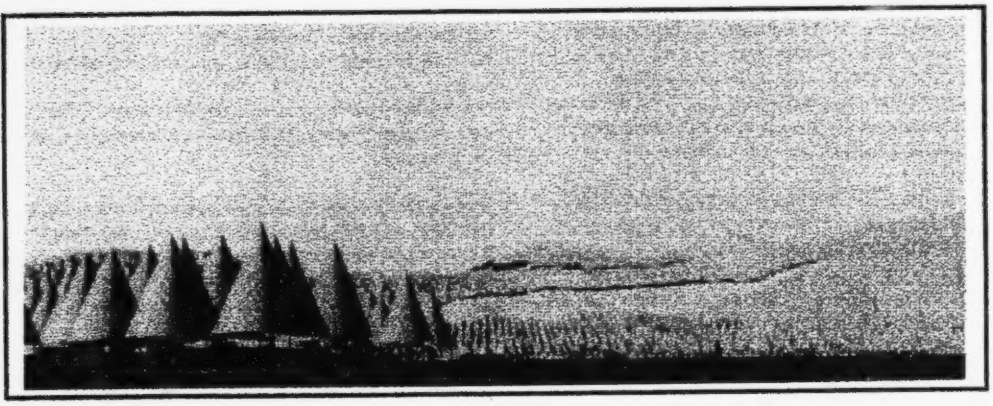

Figure 8. view from point C, looking E, f=50mm

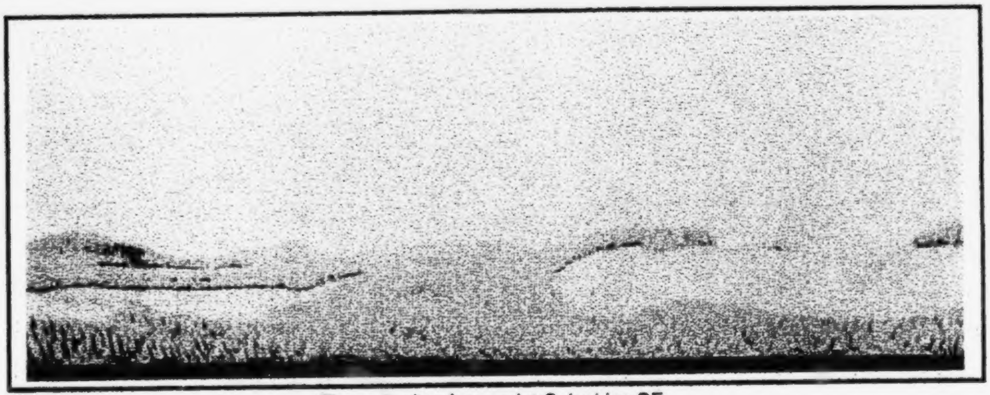

Figure 9. view from point C, looking SE

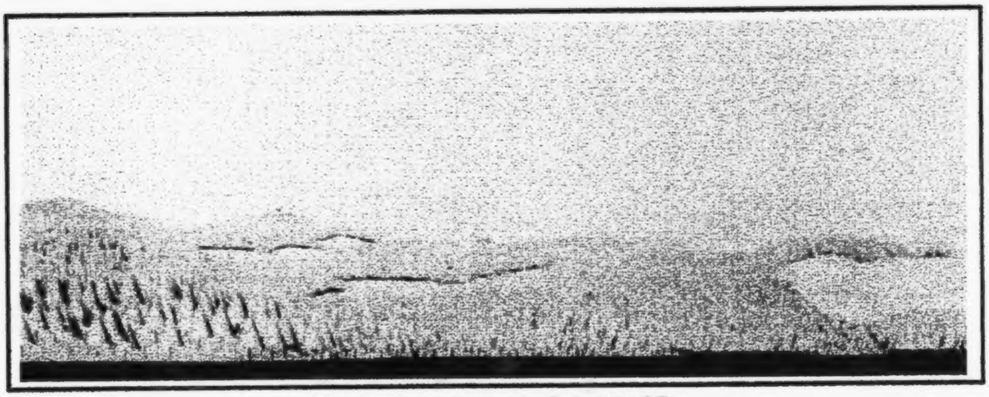

Figure 10. view from point D, looking SE

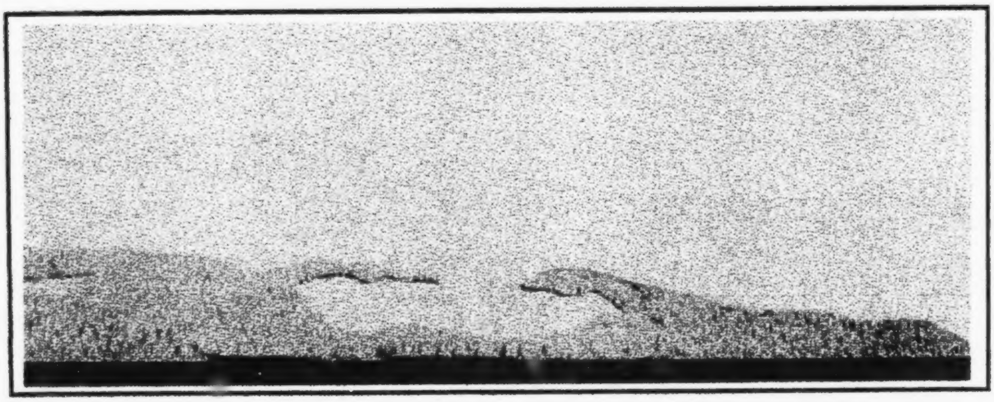

Figure 11. view from point D, looking SSE

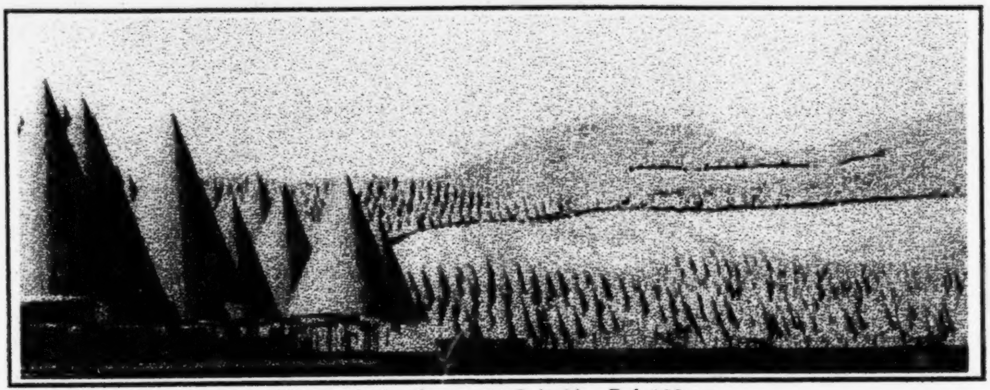

Figure 12. view from point C, looking E, f=100mm

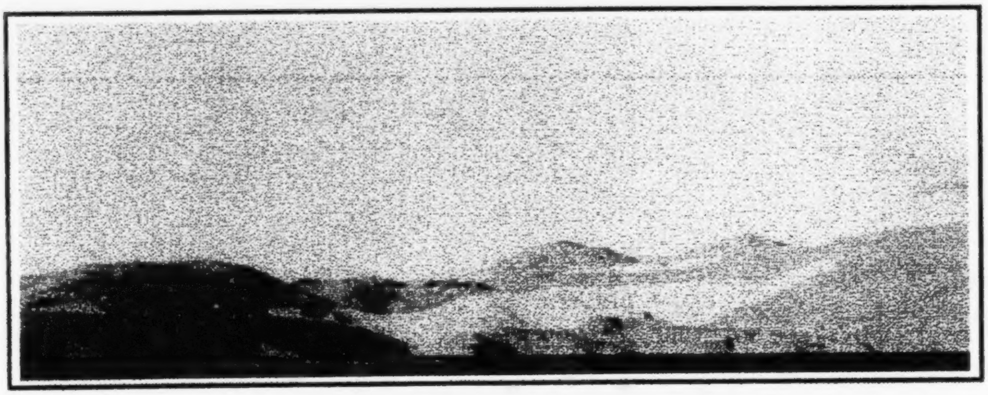

Figure 13. view from point C, looking E, f=50mm, no trees

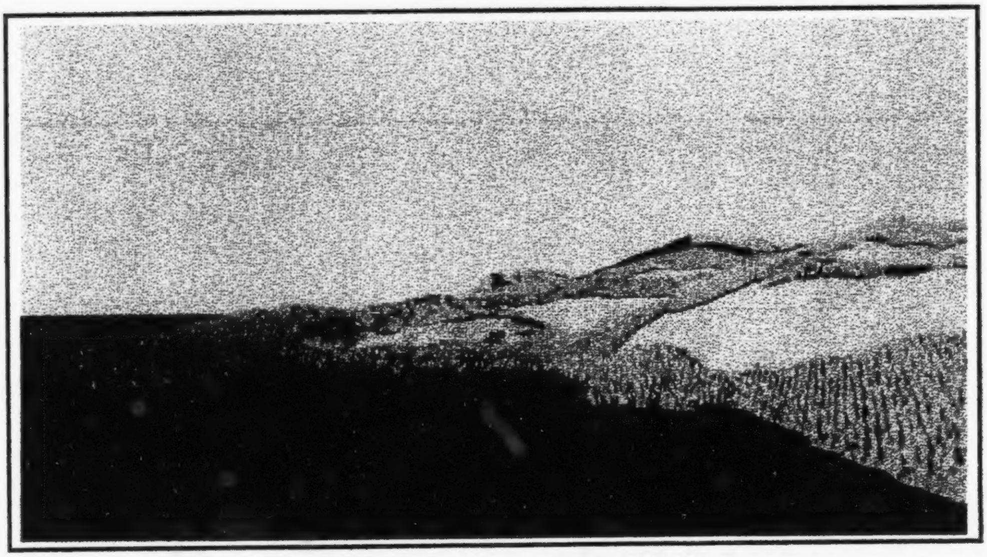

Figure 14. View from between B and C, 200m high

Figure 13 demonstrates the importance of tree symbols to the visualisation. In the figure, much more of the cleared areas is visible than in Figure 8, where tree symbols are used. The former figure also appears more realistic. The tree height is 35m.

As Figure 14 shows, the extent of the visibly logged areas increases quickly with height. Figure 14 simulates a 200m high viewpoint.

The times taken to produce the images are worth noting. Running on a Sun SPARCstation 1, the overview in Figure 4 took about 75s to produce. The image of Figure 13, without trees, required about 30s. The same view with tree symbols (Figure 8), took almost 5 minutes to draw. This indicates that some further optimisation for trees would be useful, though trees need not be added till the final view. A recent development for workstation platforms also allows images to be stored, so they can later be read in and displayed almost instantly. No graphics accelerator or 3D graphics processor was used.

The DTM pictures were to support the proposed development plan for the area. Prior to seeing the V3D pictures, the development plan had not been approved by the Ministry of Forests. Now, although the plan as a whole is not approved, parts of it have been.

7. Conclusions

The Sulphur Pass project showed that landscape visualisation by DTM produces realistic and accurate images. Once a DTM has been prepared, the images can be produced reasonably quickly, from chosen viewpoints within the DTM.

Of the variety of enhancements used to increase realism, the use of tree symbols seems to be the most effective. Not only do they make the landscape more lifelike, they also improve the accuracy of the model.

Greater accuracy could be obtained by correcting for earth curvature and refraction. These have an effect on an object's vertical position in an image. Since they are not corrected for at present, the height error remaining amounts to approximately 0.07 m over 1 km, about 1.65 m over 5 km and rises to 6.59 m at a distance of 10 km, using [Allan et al, 1968, p415] as a source. Since, in the Sulphur Pass area, the farthest view is about 5 km, and the original contour data could not be expected to be even within 2 m height accuracy, the lack of earth curvature and refraction adjustment is insignificant. It would, however, be simple to program into the projection and would hardly increase the computation time.

Another way to improve accuracy would be to allow trees in different polygons to have different average heights to correspond to their ages. This addition will be very simple, and should help to model 'green-up', the process of reforestation of logged areas.

The times taken to draw some DTMs were noted above. Clearly, significant improvements in drawing time would be obtained using a hardware accelerator. This is especially so when drawing with a graphics peripheral, rather than on an integrated workstation. Of course, cost is also a consideration.

The landscape visualisation capability should be of great use in assessing the impact of forestry developments on the landscape. It should be possible for forestry companies to demonstrate accurately the effect of logging an area, to avoid logging where damage to the environment would result; and yet not be pressured into abandoning the logging of suitable land. Indeed, the visualisation capability has already led to some areas in which logging had been forbidden, being opened up for development.

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March 1990

Automation of Visible Area Mapping for Fire Detection Lookouts

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Abstract
This paper describes a feasibility study undertaken by Alberta Forestry to determine and test the alternatives for automating visible area mapping for fire detection lookouts. Several alternatives are described that include a variety of data sources and data processing methodologies. The primary focus of the study involved the utilization of a Digital Elevation Model (DEM) supplemented by forest cover information to define different classes of non-visible areas. GIS technology was utilized for testing and displaying the results.

Custom software was written to calculate visibility values for selected data points along line-of-sight profiles obtained either from a DEM or digitized manually. The visibility values were then input into a GIS for generation of a classified visible area map. Both the influence of earth's curvature and terrestrial refraction are accounted for in the visibility algorithm. The paper identifies several data accuracy and technical processing issues which were addressed for proper utilization of DEM's in visibility analysis. A summary and list of concerns are presented.

1. Introduction

Visible area maps are commonly used within the Forest Protection Branch of the Alberta Forest Service (AFS) for the planning and evaluation of lookout tower locations. They play an important role in determining areas of responsibility for the specific lookout and for supplementary air patrols. To satisfy the requirements of determining the zone of responsibility of the lookout, visible area maps must not only display the areas seen from the lookout tower, but also the non-visible areas in a classified form.

The non-visible classification, based on specific threshold values, ie. 100 feet below the sight line, is important in determining the responsibility of the different Forest Service agencies in fire detection. Currently, the lookout tower is still responsible for forest fire detection in the areas that are up to 100 feet below its sight line. Within this area, the tower cannot directly view the landscape but can observe smoke in fire situations.

The Alberta Forest Service's existing manual process of generating the visible area maps utilizes 1:50 000 scale topographic maps for classifying the areas within a 25 mile radius of each lookout tower. For most of the 142 lookout towers, these maps were produced prior to 1970 and require extensive updating. The planned upgrading, raising and/or relocation of some towers would benefit from a more accurate and flexible visible area mapping process.

This paper summarizes the feasibility study completed by the GIS Group of the Land Information Services Division (LISD) in conjunction with the Forest Protection Branch of the Alberta Forest Service. The intent is to identify and evaluate alternatives for utilizing automated mapping and GIS technology in the production of visible area maps.

2. The Study Area

To properly evaluate the results, a study area was selected that was of immediate interest and concern to AFS staff. The Livock lookout tower, located at latitude 56°27'40" longitude 113°11'25", is in the area of relatively flat terrain in the Slave Lake Forest, southwest of the Fort McMurray region. It has recently been re-mapped and is therefore a prime candidate for analysis. The most significant landscape feature within the 25 mile radius is the Athabasca River valley in the southeast. This area also satisfied the study requirements by having DEM data readily available. DEM data is available for selected areas within the province of Alberta from the 1:20 000 Provincial Digital Base Mapping Project.

Figure 1 presents the Livock tower study area. Because of the physical extent of the study area, digital 1:250 000 positional features are utilized for reference. These include perennial hydrography, intermittent hydrography, survey townships (ATS), and access roads. Five degree line-of-sight profiles are also presented as a reference for the reader.

3. Context of the Study

The focus of the feasibility study was to evaluate a *fully automated solution* that made use of both existing DEM data and tree height information from the Alberta Forest Inventory Storage and Maintenance System (AFORISM). DEM data is available in digital format from the 1:20 000 Provincial Base Mapping Project. Forest height class codes exist as part of the green zone forest inventory data within AFORISM. The corresponding graphic polygons can easily be generated within LISD using existing software from the 1:20 000 project that supports the creation of Alberta Township System (ATS) graphic files. Custom programs support the conversion of the graphic files into a GIS format where attributes, acquired from the AFORISM database, can be linked to the individual quarter sections. Forest data for the study area is illustrated in Figure 2.

The other objective of the study was to define a *semi-automated solution* that would enhance the existing compilation process where required. This is important since much of the province, including most lookout tower locations, does not currently have DEM data available. The emphasis was on streamlining the intensive data collection process and providing software that would calculate visibility values for captured data points. This would allow us to address the immediate concerns of AFS staff, while still evaluating fully automated options. These enhancements could then gradually replace the existing manual compilation and drafting of the maps.

4. Manual Visible Area Mapping

The necessity of defining areas of responsibility require that visible area maps be categorized into **four** distinct classes. Each class is defined as a set of shaded polygons on the map. The four classes currently utilized are based on their distance below the line of sight (LOS). They are :

1. **Visible**	Above the LOS,
2. **Indirectly Visible**	Up to 100 feet below the LOS,
3. **Screened**	100 to 300 feet below the LOS,
4. **Blind**	More than 300 feet below the LOS.

The visible area maps also include positional base map information such as perennial hydrography, access roads, and the ATS fabric (townships, sections). These reference features are obtained from 1:50 000 NTS maps.

The existing process for generating visible area maps involves splicing 1:50 000 map sheets together to provide a complete map of the tower range. Five degree profiles are then drawn on this coverage map. Each line of sight profile extends 25 miles from the tower location. Seventy-two profiles are used for each tower location. In cases where extreme terrain is involved, additional profiles are used. Cross sections are then generated for each profile by recording where profiles and contours cross. An average forest cover tree height is assumed, based on the forester's understanding of the study region, and the elevation of the points is adjusted accordingly. Twenty metres was used for the Livock region. In order to account for the earth's curvature and terrestrial refraction, a specially designed curve template is used to assess visibility from the cross-section graphs. The equation used for computation of the corrected

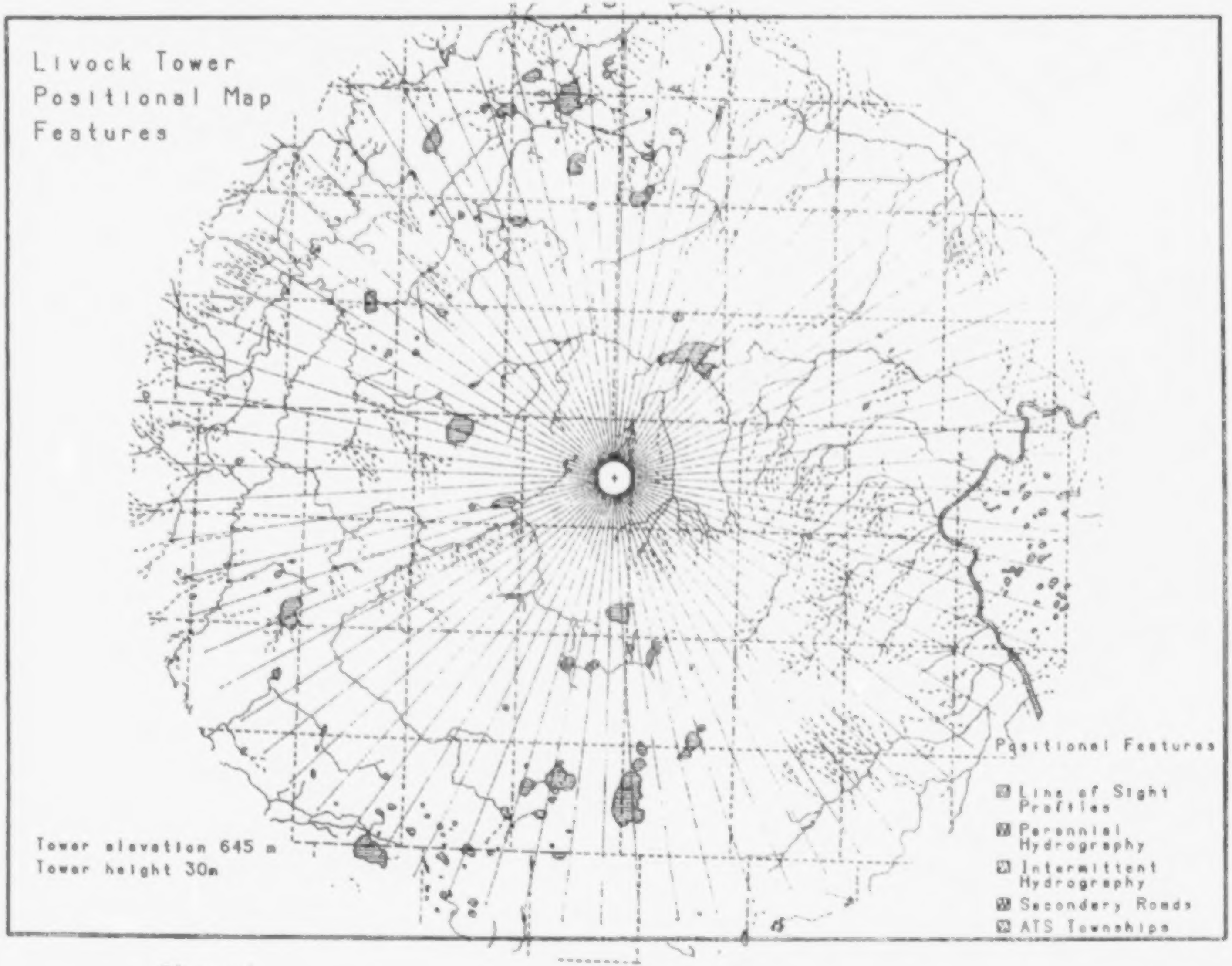

Livock Tower
Positional Map
Features
Tower elevation 645 m
Tower height 30m
Positional Features
Line of Sight Profiles
Perennial Hydrography
Intermittent Hydrography
Secondary Roads
ATS Townships

Figure 1

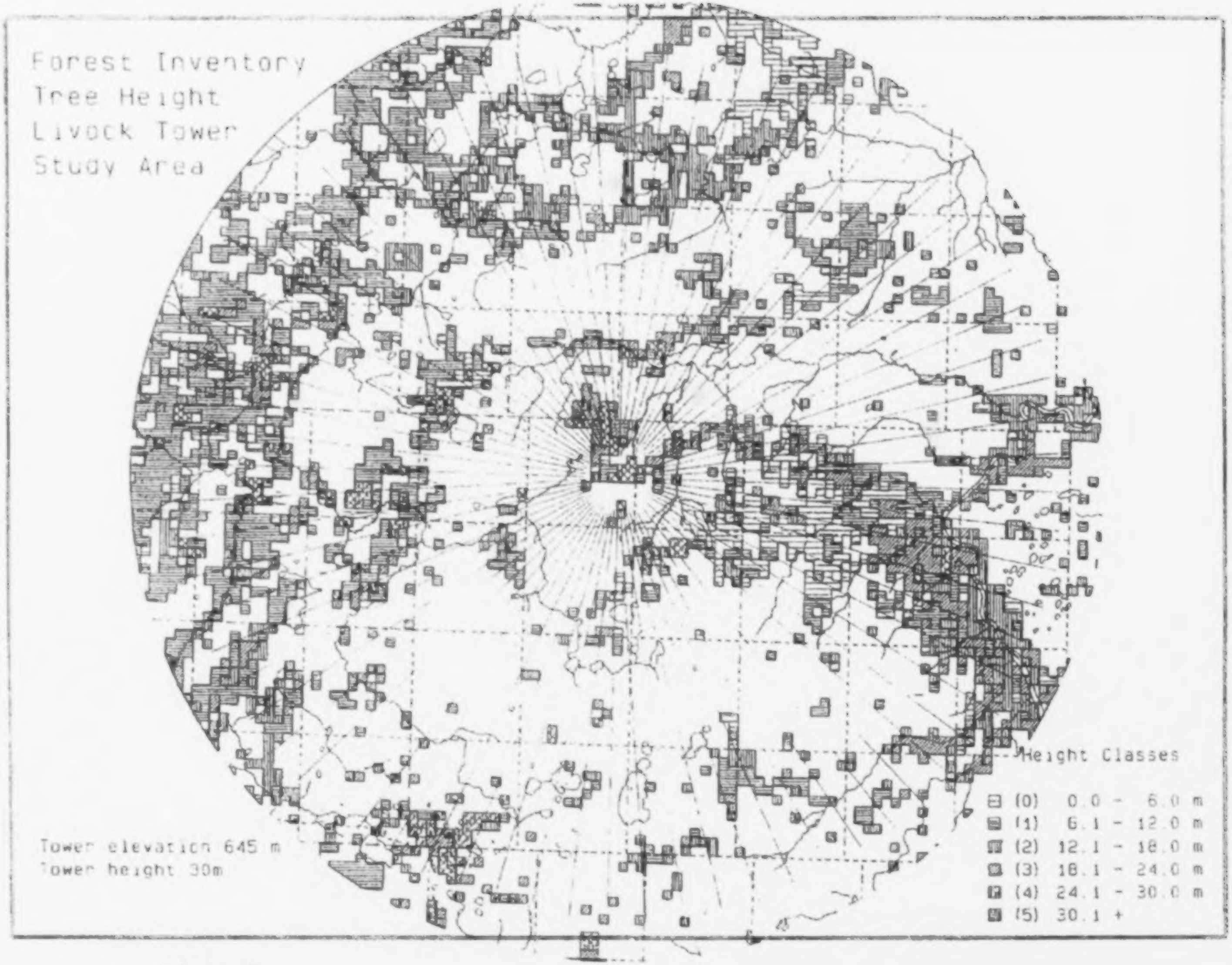

Forest Inventory
Tree Height
Livock Tower
Study Area
Tower elevation 645 m
Tower height 30m
Height Classes
▤ (0) 0.0 - 6.0 m
▤ (1) 6.1 - 12.0 m
▥ (2) 12.1 - 18.0 m
▩ (3) 18.1 - 24.0 m
▧ (4) 24.1 - 30.0 m
▨ (5) 30.1 +

Figure 2

elevation and for the design of the curve template, is :

$$Hc = Hm - 0.87d^2/2r$$

where Hc is the corrected elevation,
Hm is the measured elevation,
d is the distance from the lookout,
R is the earth's radius.

The use of this adjustment equation is important as the correction for ground elevation at a 25 mile distance exceeds 300 feet. Figure 3 illustrates the graphical process of determining visible area zones along a profile.

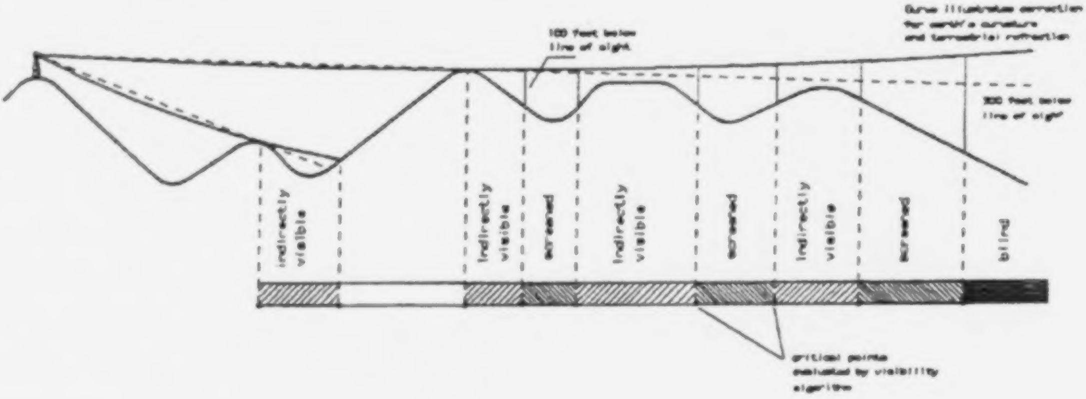


Figure 3 Non-visible area classificaiton

time, money, and manpower savings. Utilizing digital data allows also for new display options, and further model manipulation to derive other mapping products, such as 3-D perspective views, landscape planning maps, etc. The development and implementation of an automated method using a DEM can also offer added flexibility when considering movement of the lookout tower to a new location, or when considering raising it. As well, GIS techniques will afford the integration of other data sets, i.e., forest tree heights, in conjunction with elevation data for proper height adjustment of the viewing landscape.

Initially, in this manual process, only the points on the profile lines that separate the visibility zones are calculated. The threshold value points, -100 feet and -300 feet, are then joined from profile to profile by a manual interpolation process that utilizes contour lines and associated terrain features to form the polygons of a given visibility class. The visible area map generated by this manual method for Livock tower is presented in Figure 4.

5. Automated Alternatives

The manual process of defining visibility is a rather laborious procedure and the accuracy of the results depends on many factors such as :

scale of the contour map used,
interval and accuracy of the contours,
density and accuracy of the profiles constructed,
interpretation skill of map user (Yoeli, 1985).

The introduction of computerized methods could enhance the accuracy of constructing profiles and assessing visible areas, providing that the DEM is dense enough and that software algorithms are chosen correctly for the application. Automation of the process can also provide considerable

5.1 Utilization of DEMs

The building of a DEM model of sufficient accuracy to provide for analysis of the entire study area is a critical part of the process. The most accurate data available for the study area is a DEM from the 1:20 000 Provincial Digital Base Mapping Project. 1:20 000 DEM data is available in two formats, original measured (raw) and re-interpolated.

The original measured data set is captured photogrammetrically from 1:60 000 aerial photographs. Data points are captured for a regular grid across each map sheet. This regular grid may vary from a 75 metre interval to 200 metres, depending on the terrain. The regular grid is supplemented by spot heights, breaklines, and excluded area points. Spot heights represent high and low points across the map sheet, i.e., hill tops and valley bottoms. Breaklines are defined by distinct changes in slope, commonly occuring hydrography and ridges. Excluded areas define regions where no data is captured, i.e., perennial lakes. The raw data model may contain anywhere from 30 000 to 60 000 points per map sheet.

In an effort to provide consistent DEM data for the entire province, this raw data is processed with the Stuttgart

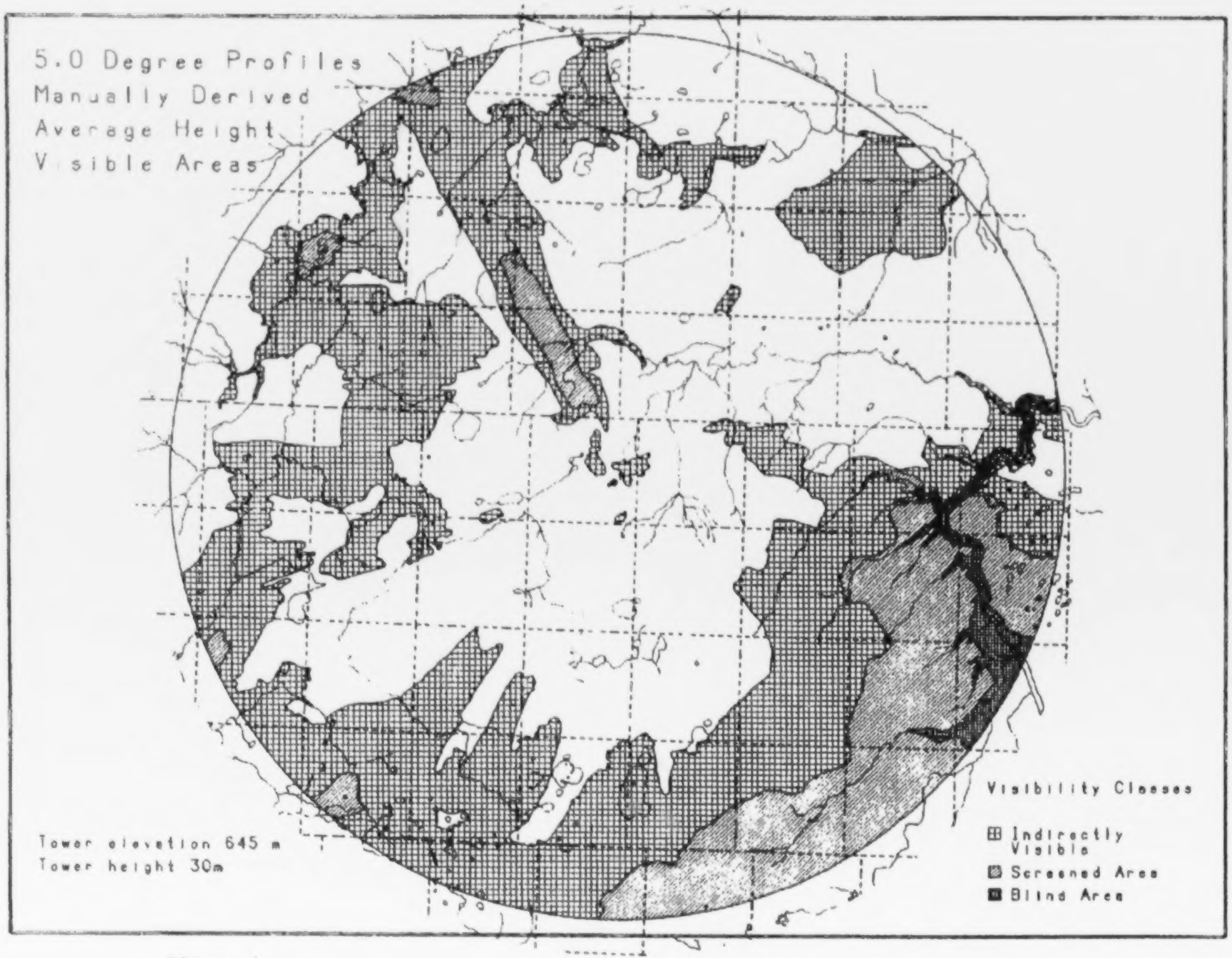
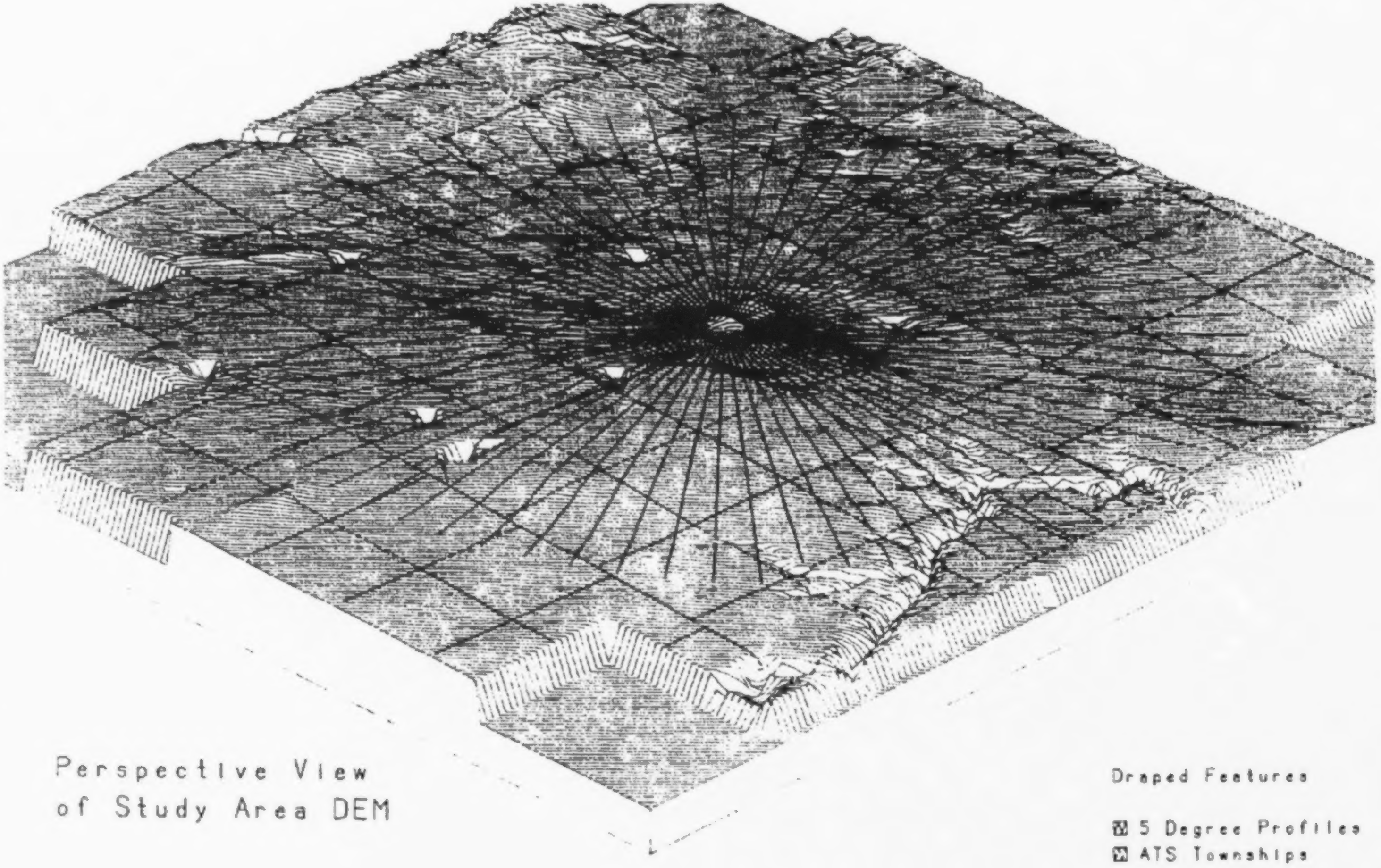

5.0 Degree Profiles
Manually Derived
Average Height
Visible Areas
Tower elevation 645 m
Tower height 30m
Visibility Classes
⊞ Indirectly Visible
▨ Screened Area
■ Blind Area

Figure 4



Perspective View
of Study Area DEM

Draped Features
▩ 5 Degree Profiles
▩ ATS Townships

Figure 5

Contouring Package (SCOP). This eliminates model seams from the data, as well as providing the capability to re-interpolate and re-distribute the regular grid at any desired interval. The number of data points for a map sheet of SCOP DEM data will vary depending on the specific grid interval. Obviously, a 25 metre grid interval will result in many more data points per map sheet than a 100 metre grid interval. Both DEM data sets are available for selected areas from the Surveys and Mapping Branch of LISD. Complete coverage for the province is not scheduled until 1995.

One other method exists for utilizing a DEM model for visibility analysis. Often DEM models can be generated by digitizing contour information from hardcopy topographic maps, ie. 1:50 000 NTS maps. Data can be captured either as random points along the contours or as complete contour lines. Both methods result in a set of random elevation points. These random points can then be used to generate a Triangular Irregular Network (TIN). Most geo-processing software affords this capability. A regular grid data set, commonly referred to as a DEM, can then be interpolated from the TIN. Again,most geo-processing software provides this function. These methods of data capture are most often used when DEM data is unavailable. The DEM generated from this process is usually much less accurate than conventional DEM's as less known data points are used in its creation. This method is consistent with the existing manual process undertaken by the Forest Protection Branch. Often, it remains the only alternative for areas in which no DEM data is available. Results from this method are compared with full DEM utilization later in the paper.

Because of processing constraints with existing geo-processing software available within LISD, the SCOP DEM data was utilized for the Livock study area. A total of 36 1:20 000 DEM data files were required, each with a 200 metre grid interval. These files were merged to obtain a lattice file that was 400 rows by 400 columns. This totalled 160 000 data points. An arbitrary elevation value of 480 metres was assigned to points within excluded areas. This was required to account for the larger lakes within the study area that were provided without an elevation.

Utilization of the pre-processed DEM data greatly reduced the data handling requirements in building the DEM file for the entire study area. The use of the raw DEM data could not be considered due to the sheer number of points involved. Based on a conservative average of 35 000 points per 1:20 000 map sheet, approximately 1 260 000 data points would be needed for the study area. Users will be hard pressed to find any GIS software that will efficiently handle this amount of DEM data. Figure 5 illustrates the complete DEM for the study area presented as a perspective surface with ATS townships and 5° line of sight profiles draped onto the surface.

5.2 Computer Visibility Analysis

Computer visibility programs are typically only capable of analyzing cells, and the maximum density of analytical coverage is a function of the cell size (Felleman, 1979). A rigourous solution would require creation of a sightline for every grid point and interpolation of the intermediate sightline points between grid points. Such precise analysis is very time consuming and not always necessary, depend-

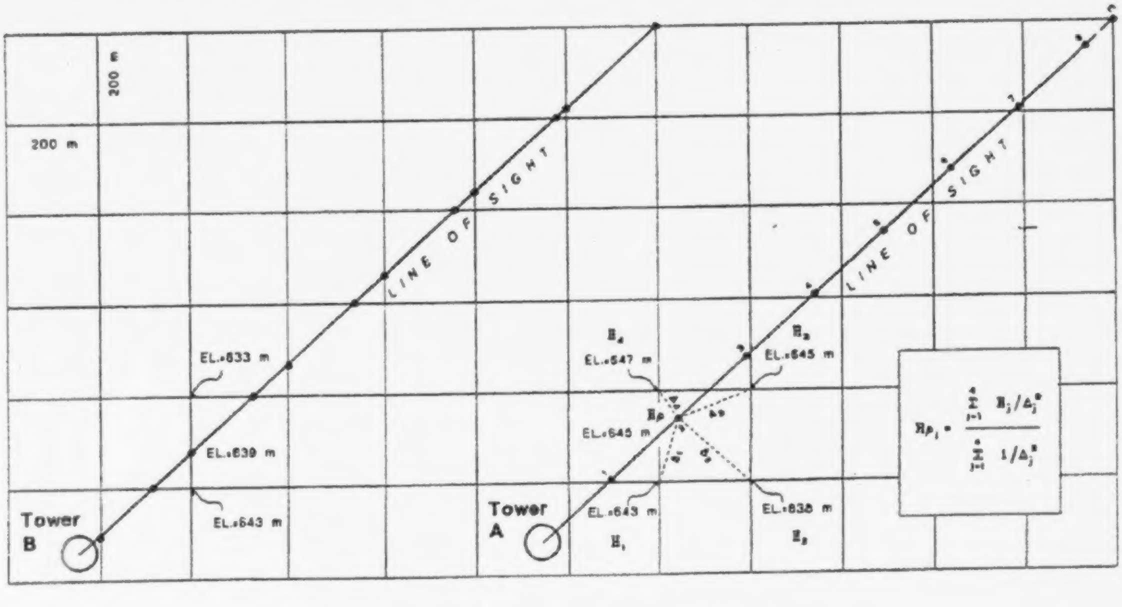


Figure 6 Alternatives for interpolating the DEM data model

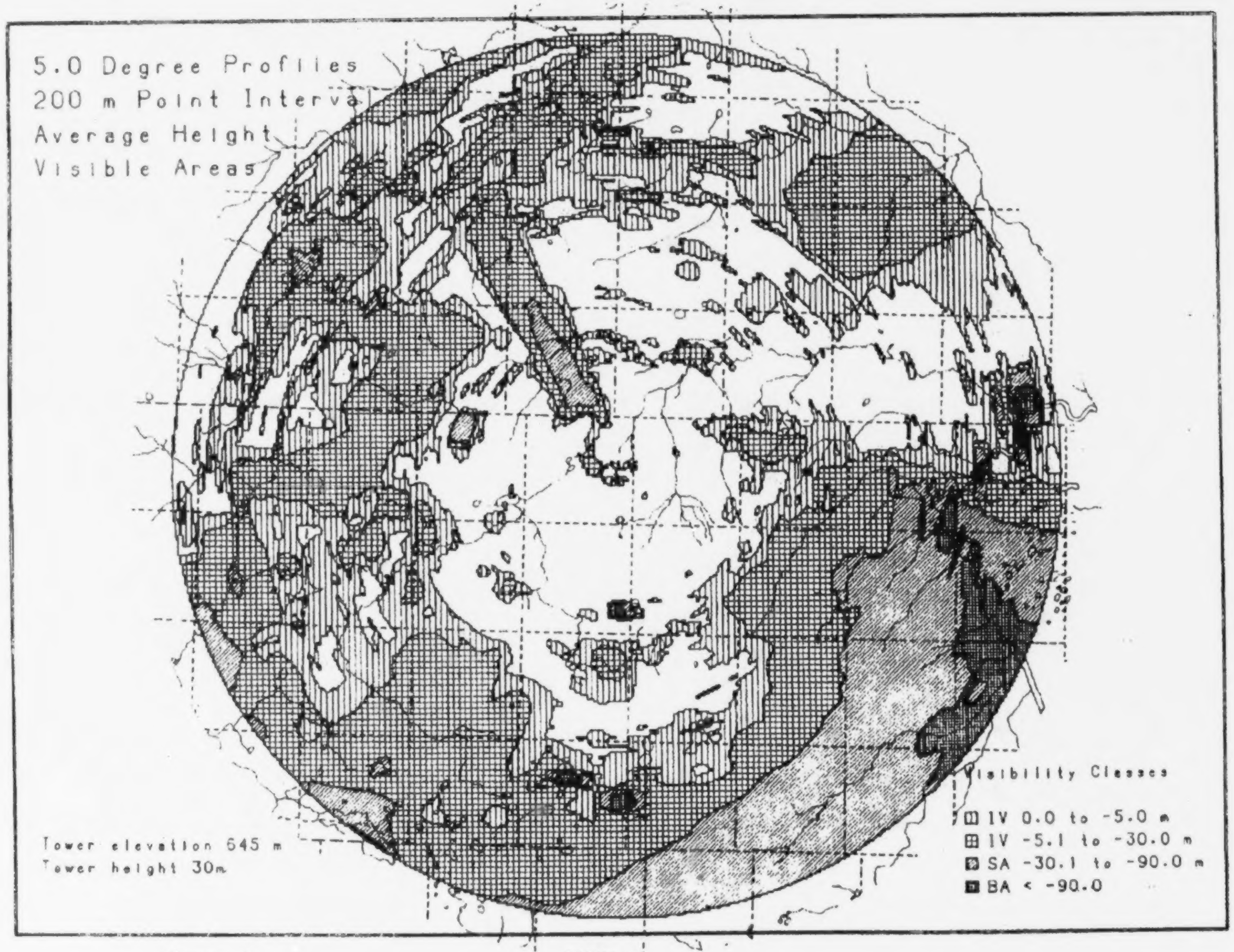

5.0 Degree Profiles
200 m Point Interva
Average Height
Visible Areas
Tower elevation 645 m
Tower height 30m
Visibility Classes
▥ IV 0.0 to -5.0 m
⊞ IV -5.1 to -30.0 m
▨ SA -30.1 to -90.0 m
■ BA < -90.0

Figure 7

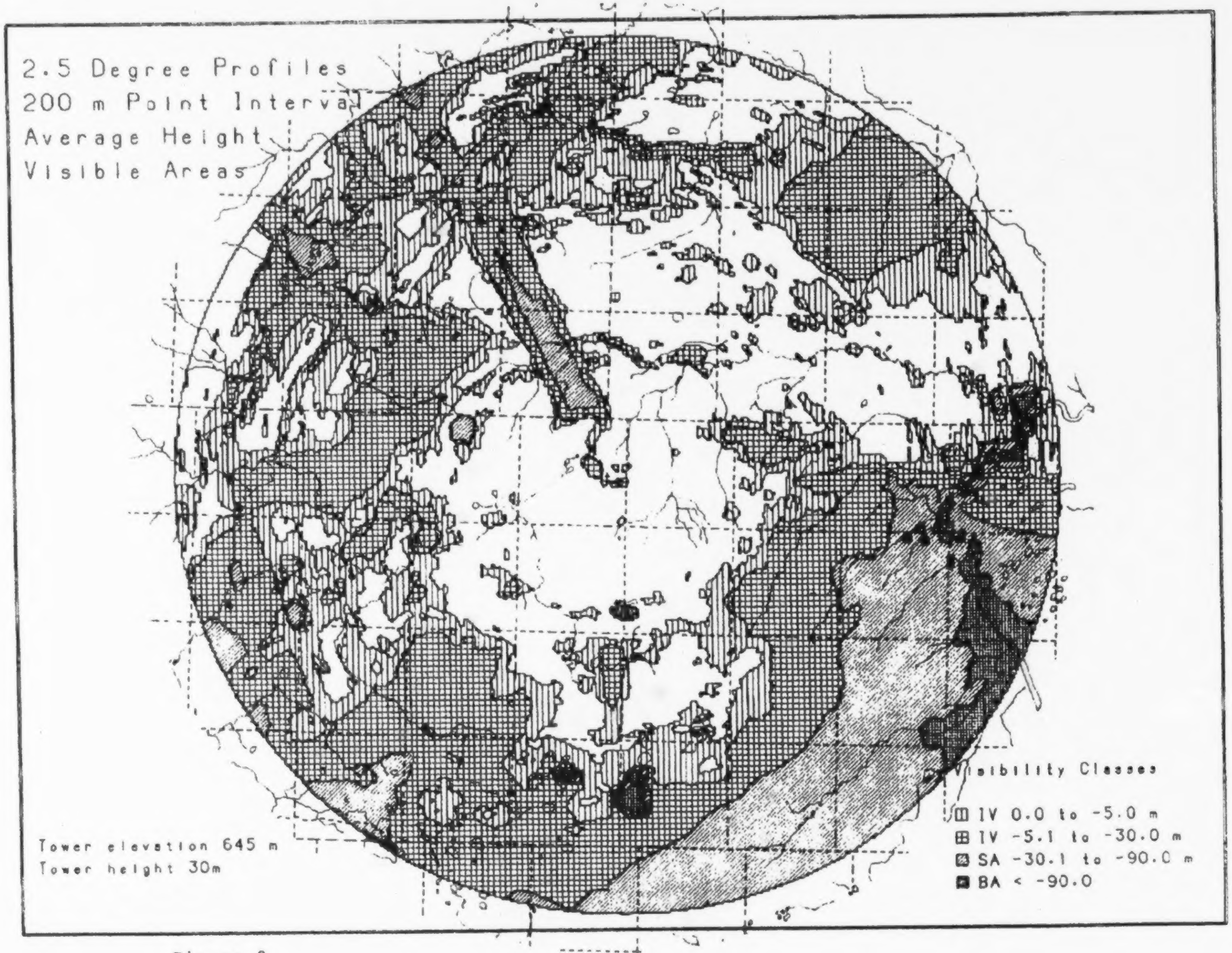

2.5 Degree Profiles
200 m Point Interval
Average Height
Visible Areas
Visibility Classes
▥ IV 0.0 to -5.0 m
⊞ IV -5.1 to -30.0 m
▨ SA -30.1 to -90.0 m
■ BA < -90.0
Tower elevation 645 m
Tower height 30m

Figure 8

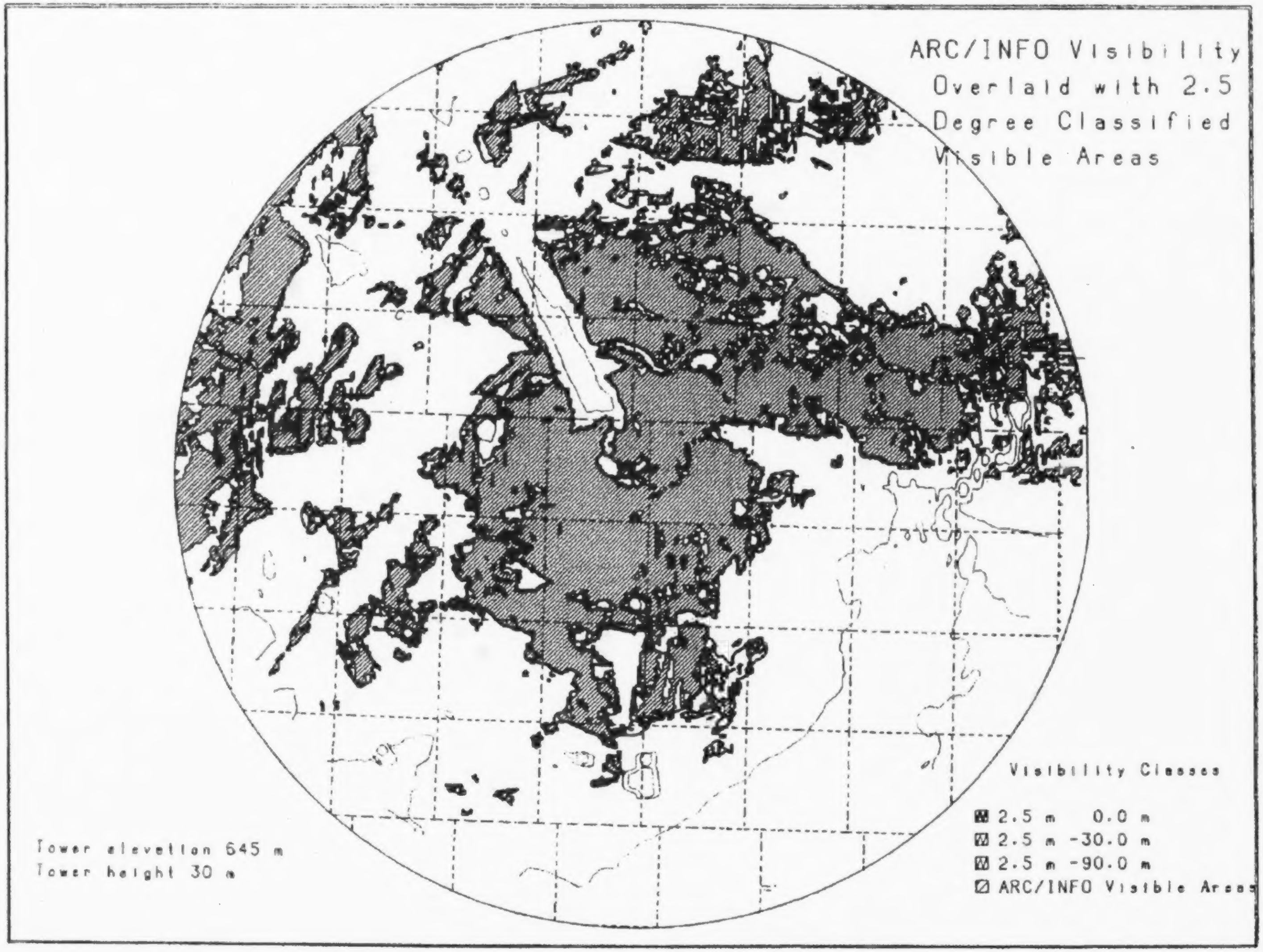

ARC/INFO Visibility
Overlaid with 2.5
Degree Classified
Visible Areas
Visibility Classes
▩ 2.5 m 0.0 m
▨ 2.5 m -30.0 m
▨ 2.5 m -90.0 m
▨ ARC/INFO Visible Areas
Tower elevation 645 m
Tower height 30 m

Figure 9

ing on the accuracy requirements of the application. As a framework for reference, the ARC/INFO software, available within LISD, was used to generate visibility areas for the Livock DEM. This resulted in the generation of approximately 3 200 polygons defined as either visible or non-visible. Seventy-five percent of those polygons were smaller than 4 grid cells (160 000 square metres). For visual clarity, these were eliminated using a threshold value of 180 000 square metres. This resulted in a less noisy image with no obvious change in pattern.

Because of classification and accuracy requirements, a simpler algorithm for determining visibility has been implemented. The aim was to provide more accurate results than was currently achieved by the manual approach, but without the significant overhead of data capture and CPU processing requirements. As well, more flexibility was required for the definition of model parameters, such as tower height, location, and non-visible class thresholds.

Similar to the manual process described previously, the algorithm utilized is based on the use of regularly spaced data points along line of sight profiles constructed at predefined intervals. Instead of using 5° profiles constructed manually from the intersection points with contour lines, the program generates profile lines at any chosen angle increment and with any desired density of points along the line, i.e., 2.5° profiles with points every 200 metres. For each point along the profile the elevation is calculated from the DEM (the use of a TIN is also possible here). These elevations are then processed with the visibility algorithm, accounting for curvature of the earth and terrestrial refraction, to determine a visibility value for that point, i.e., -123.45 metres. Points that are visible are given a value of 0.0. Subsequently, the user is provided with visibility values for points regularly spaced along a profile from the lookout tower. A data file is created that identifies each point by UTM easting and northing along with original Z elevation, profile ID, and visibility value. The intent is that this data file can then be taken to an appropriate software package for generation of classified areas or contours. The process is not constrained by any specific GIS software package.

Initial results indicate that CPU processing times are significantly less than those required by the approach of analyzing each cell (CPU times in the order of hours). As well, this approach provides results well within the current accuracy requirements of the Forest Protection Branch, and very closely matches those results generated by the cell approach. Figure 6 illustrates both approaches for interpolating the DEM.

Some preliminary testing was undertaken using several different profile intervals and point densities. Original processing using 5° profiles and a 100 metre point interval yielded results far more accurate than the manual methods, but not as well defined as the cell approach. Further testing has identified that for the visible area mapping application, 2.5° profiles with a 200 metre point interval will result in sufficient accuracy to generate visible area zones as required. This very closely matches the results obtained from the cell approach. Further testing is intended to help define the optimum parameters for processing study areas with different terrains and landscapes. Figure 7 and 8 present visible areas generated using 5° and 2.5° profile intervals with a 200 metre point interval. Both models utilize an average 20 metre tree height consistent with the manual approach. Figure 9 compares the "cell" approach results generated from the ARC/INFO software with contour lines interpolated from the visibility model. Contour lines of 0, -30 metres (≈100 feet), and -90 metres (≈300 feet) are presented. A profile interval of 2.5° with a 200 metre point spacing was used to generate the visibility values.

Table 1. A Comparison of Non-Visible Areas for All Study Area Maps (Areas in sq. km)

High values are bold. Low values are underlined.

		VISIBLE CLASSES				
		-90+	**-30+**	**-5+**	**0+**	**TOTAL**
5.0°/200 m Avg. Height	POLYS	12	19	49	110	247
	AREA	**107.51**	623.35	561.21	**1152.94**	3445.01
5.0°/Digit Avg. Height	POLYS	**23**	42	47	135	273
	AREA	78.80	567.06	1382.17	849.12	2877.15
2.5°/200 m Avg. Height	POLYS	17	25	52	147	315
	AREA	98.05	656.66	1528.79	1062.38	3345.88
2.5°/200 m Tower Raised	POLYS	16	22	57	142	305
	AREA	81.94	95.22	1451.19	1095.82	3224.17
2.5°/200 m Height Adjusted	POLYS	21	**56**	**93**	**306**	**571**
	AREA	69.32	**856.38**	**2190.80**	782.56	**3899.06**

5.3 Other Factors Influencing Visibility Analysis

Integration of Forest Cover Information

Line of sight profile analysis for determining visibility zones can incorporate many parameters into the visibility model, including the location of the observation tower, changing tower heights, atmospheric and surface characteristics, and vegetation information. Some of these elements have a very significant influence on the final visible area mapping results. It is imperative that one always takes into consideration the relationship between the accuracy of the components and the final representation of visibility areas.

Perhaps the most obvious parameter that can affect the results of the visibility analysis is the use of forest cover tree height data. As previously identified, tree height data was obtained from the AFORISM system for the study area. Because of constraints on the availability of digital forest stand boundary data, information was retrieved based on an ATS quarter section aggregation. Standard AFORISM tree height codes are based on 6 metre class intervals, i.e., Class 0 is 0.0 to 6.0 m, Class 1 is 6.1 to 12.0 m, etc. Boundaries for the quarter sections were generated using custom LISD software. Approximately 19 200 quarter sections are included in the Livock study area. Figure 2, identified earlier, presents the forest cover tree height classifications for the study area.

After elevation values were determined for the profile points (28 944 in total), they were overlaid with the forest height polygons to determine the tree height code for every point. This area is not heavily forested and does contain several areas of muskeg that are assigned no tree height code. Accordingly, not all points are affected by a tree height code. The elevation value was then adjusted using the middle value for the range, i.e., Class 0 - 0.0 to 6.0 is 3.0. This adjusted elevation value was then utilized in the visibility analysis. The results of the height adjusted visibility analysis is presented in Figure 10. Note that many areas previously classified visible are now found to be indirectly visible or screened once tree height has been taken into account.

Accuracy of Input Data

The predominant factor affecting the results of a visibility analysis is clearly the accuracy of the input data. Our testing has shown that this type of analysis is very sensitive to variations in the input parameters. These include :

location of the tower,
elevation at the base of the tower,
height of the tower,
accuracy specifications of the DEM data,
accuracy specifications of the forest cover data,
processing algorithms (curvature, refraction, contouring).

We have found that the exact tower location and height cannot always be easily determined. In our case the position of the Livock lookout tower stored in the forestry database, as latitude and longitude, proved to be 400 metres down slope from the true location, as identified in a digital 1:20 000 NTS map sheet. Such an error can significantly distort the definition of the visibility zones. As well, the elevation at the base of the tower was listed at 645 metres. However, our DEM identified the elevation as 646.5 metres. Given a tower that is only 30 metres high, and is situated in a local area of dense, high trees (24.1 to 30.0 metres), differences in mere metres can also greatly affect the results of the visibility analysis.

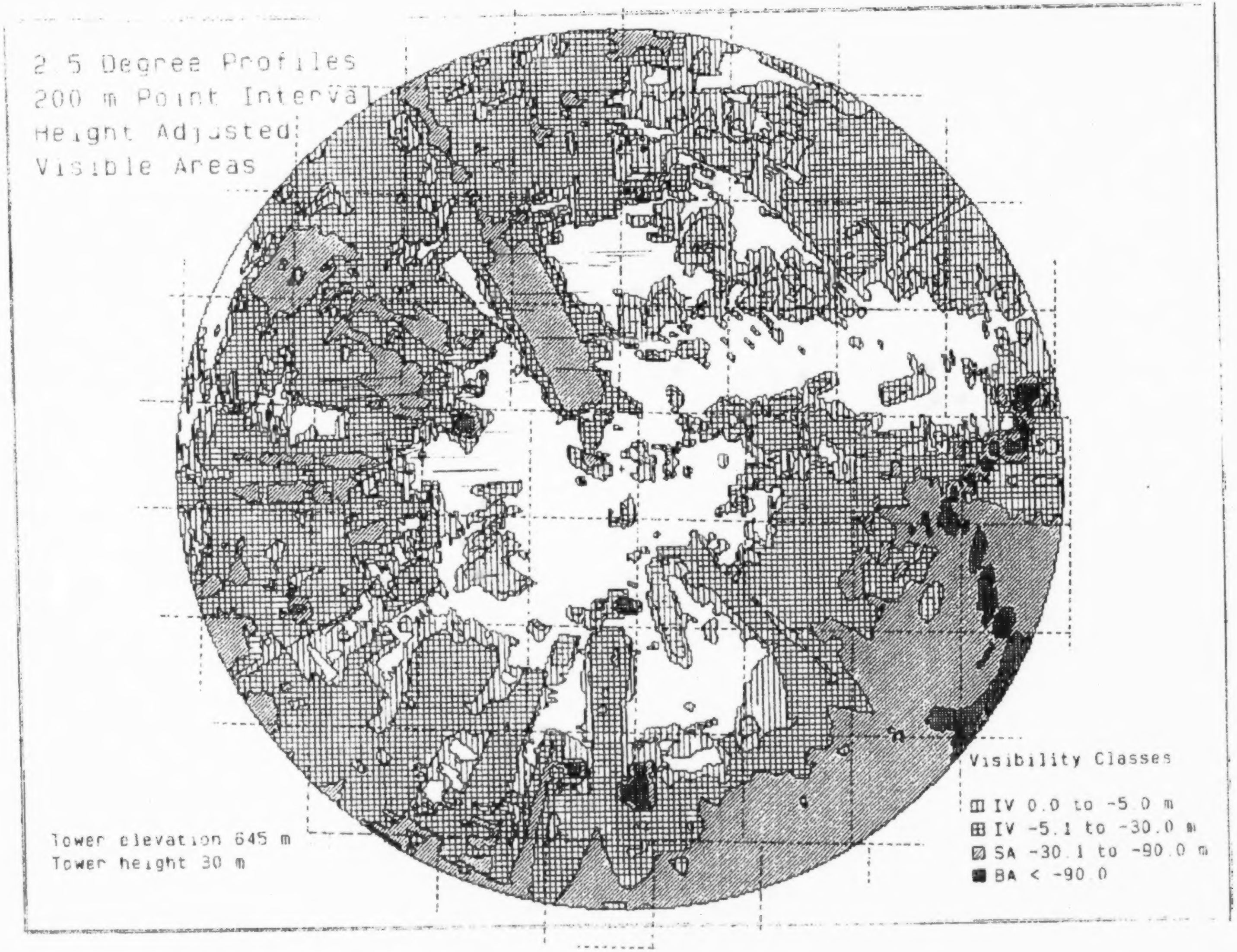
Consideration of the accuracies of the DEM and the tree height information must also be taken into account. The 1:20 000 DEM utilized in this study has an accuracy of ± 5 metres in forested areas and ± 3 metres in open areas. The forest height information has an accuracy of ± 3 metres given the 6.0 metre class intervals. It becomes quite obvious that in some situations these variables can combine to reflect unrealistic representations of the landscape.

Figure 11 illustrates the sensitivity of the model by presenting visible areas for the Livock study area where the lookout tower has been raised 5 metres. A 2.5° profile interval using a 200 metre point interval, and an average tree height of 20 metres was used.

6. Semi-Automated Method

The fully computerized analysis alternative operates well when a DEM of a sufficient accuracy is available, and elevation profiles can be automatically generated. However, visibility analysis to define critical points can also be performed when no DEM is available. This is done by digitizing points along profiles that cross contours on a topographic map. In this scenario, the visibility model can determine visibility values for the captured points, and interpolate thresholds values, i.e., -30 metres, along the profile. These points can then be provided in map form, points supplemented by threshold contours, as a guide for the manual drafting of visible areas. In this case, just as in the fully manual method, terrain features and contours from the topographic map are utilized for interpolating between profiles. This methodology would greatly enhance the data capture and visibility calculations within the operational confines of the existing manual process.

To support such a process, a specialized digitizing program was written to allow for the efficient entry of contour points along profiles. Specific cursor buttons control the entry of elevations and automatically calculate the UTM easting and northing for the data points. The map sheet must first be registered in latitude and longitude or a UTM projection. Several options exist that allow the user to increment and decrement elevation values automatically, review existing points, delete points, and change input units dynamically between feet and metres. The data points are written to a data file that is utilized in the visibility programs. As well, another program has been developed to generate labelled cross-sections for the profile points. This supports the comparison of data points from any data capture method, digitized, DEM, and tree height adjusted. The development of these programs in support of a semi-automated method has significantly reduced the time and manpower required to input and process the data.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Tower height 30 m
Visibility Classes
IV 0.0 to -5.0 m
IV -5.1 to -30.0 m
SA -30.1 to -90.0 m
BA < -90.0

Figure 10

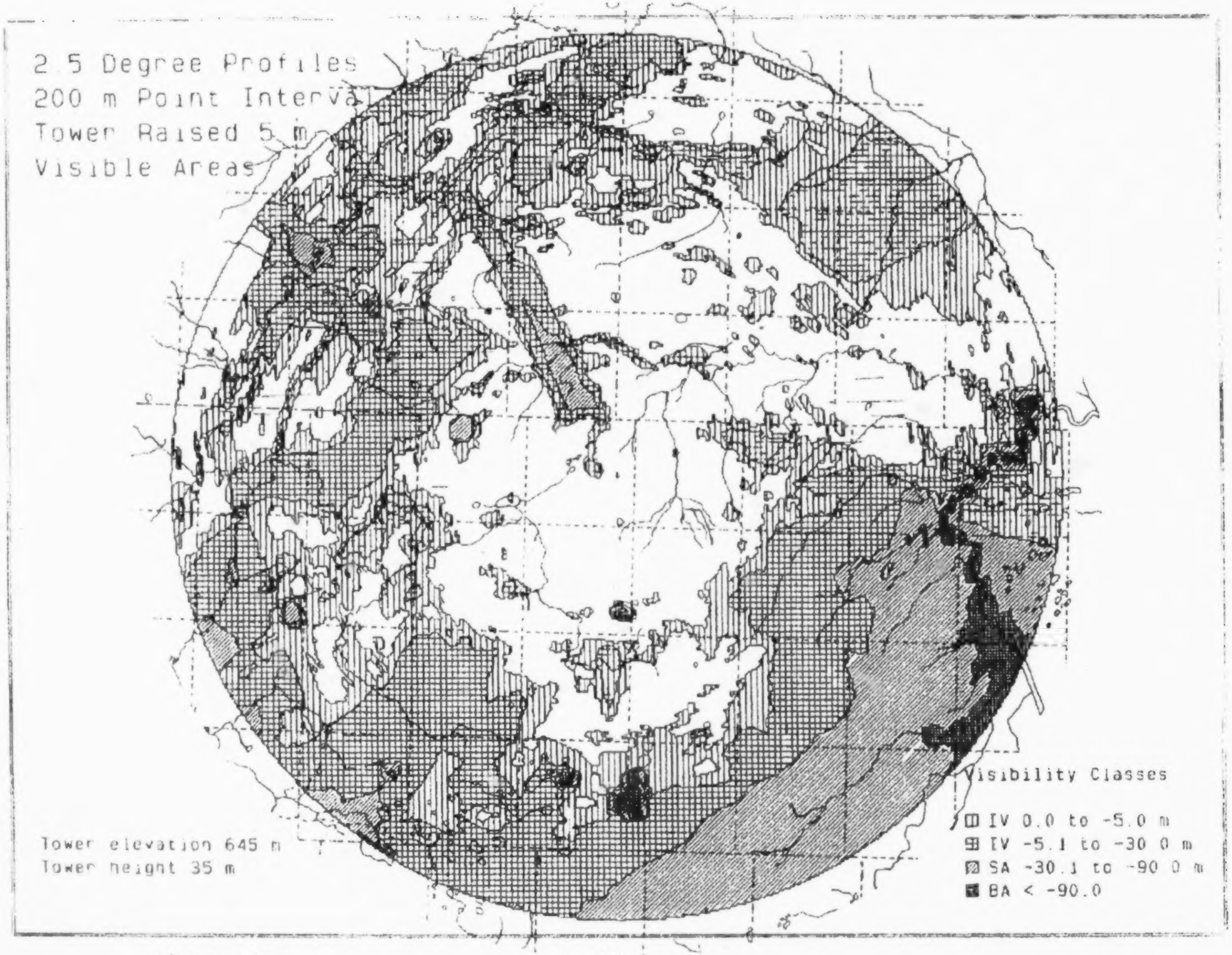
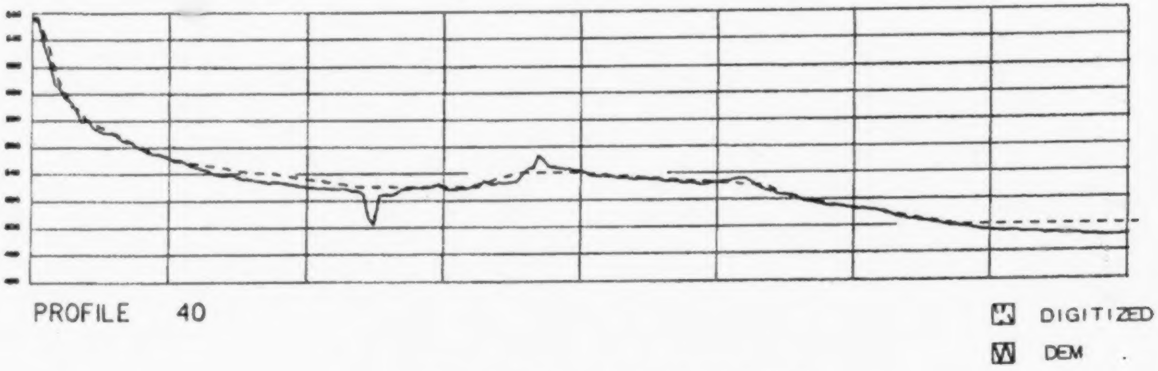

2.5 Degree Profiles
200 m Point Interval
Tower Raised 5 m
Visible Areas
Tower elevation 645 m
Tower height 35 m
Visibility Classes
IV 0.0 to -5.0 m
IV -5.1 to -30.0 m
SA -30.1 to -90.0 m
BA < -90.0

Figure 11

CROSS-SECTION COMPARISON OF DATA MODELS

DEM vs digitized points



DEM vs tree height adjusted DEM

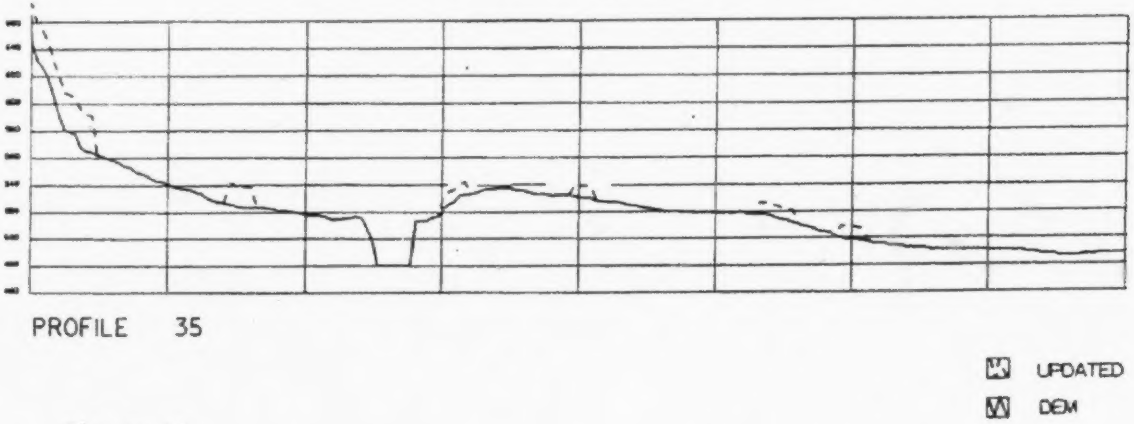


Figure 12

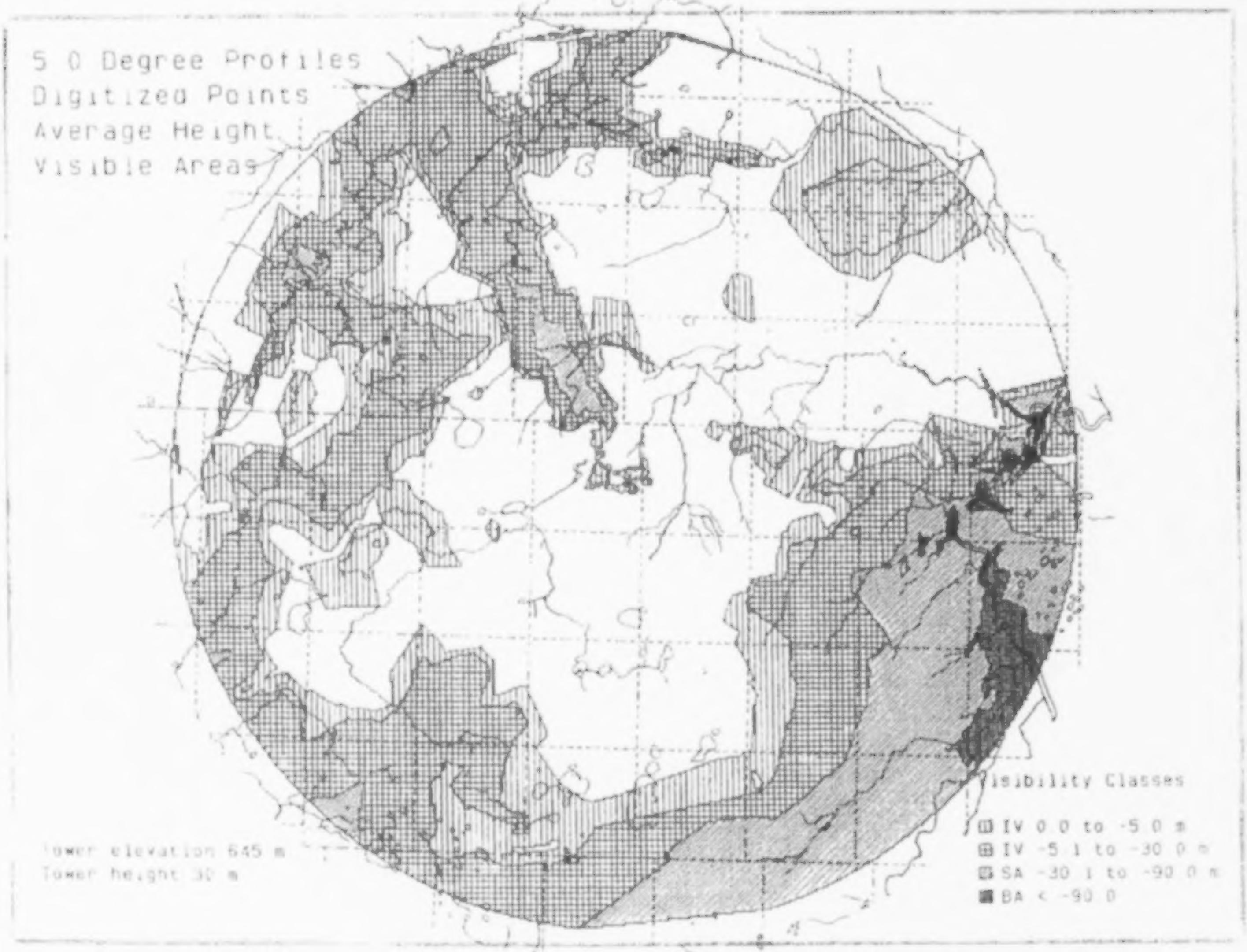

5.0 Degree Profiles
Digitized Points
Average Height
Visible Areas
Visibility Classes
▥ IV 0.0 to -5.0 m
▦ IV -5.1 to -30.0 m
▧ SA -30.1 to -90.0 m
■ BA < -90.0
Tower elevation 645 m
Tower height 30 m

Figure 13

To fully debug and test these routines, as well as provide a comparison for other visibility analysis options identified earlier, the Livock area was digitized using 5° profiles. The resultant data file was run through the visibility model. Figure 12 illustrates the difference between profile cross-sections from the 1:20 000 DEM data and the digitized data and the tree height adjusted DEM data points. Note the differences between the DEM model and both data sets. The visibility zones derived from the digitized points are presented in Figure 13. A comparison of all visible area maps generated in the study is presented in Table 1. The number of polygons and their total areas (in sq. km.) are presented for each visibility class. Note that the tree height adjusted map contains the most polygons covering the largest areas. The visible area map generated from the digitized points with the semi-automated approach contains the least amount of non-visible area. As well, the change in tower height of 5 metres for the 2.5° profiles reflects a gain of 121.71 sq. km. in visible area.

7. Summary and Conclusions

With the increasing availability of accurate digital data many manual, time-consuming processes can be enhanced or replaced with automated and semi-automated alternatives. GIS technology allows the utilization and integration of data from a variety of databases providing users with advanced capabilities and options for addressing complex data processing problems.

The feasibility study reviewed in this paper identifies one such application where the integration of GIS technology and multiple data sources has provided foresters with alternatives for carrying out their daily operations. The identification of visibility zones from lookout towers plays an important role in defining responsibilities for fire detection. The priority associated with fire detection and resource allocation necessitates that the most up-to-date tools and methodologies be evaluated and utilized wherever appropriate.

This study clearly indicates that several alternatives are functionally feasible for enhancing the visible area mapping process. In particular, the utilization of DEM data and forest cover information can greatly enhance the accuracy and quality of visible area maps. As well, semi-automated options, if implemented properly, can also offer substantial savings in manpower and turnaround time. Conservative estimates indicate a potential savings of 12 man days per lookout tower for the generation of the visible area maps. This will reduce the production time by 75 % considering a current average turnaround time of 16 man days per lookout map! Conversion to a fully automated solution will yield more accurate results, but most likely will not result in lowered manpower requirements.

This study has also identified several issues and concerns that need to be addressed before a fully automated alternative can be operationally implemented. Most of these relate to accuracy of the input data and operating parameters. These issues can only be addressed through pilot projects undertaken in conjunction with forestry application staff.

Several activities have been identified throughout the course of this study that should be pursued in the near future. These activities are focused on technical considerations and will require the support of senior management for maintaining a priority for future research and development. They include :

field checking of results by visiting selected lookout towers,
the analysis of other study areas with a greater diversity in terrain,
refinement of the algorithms to deal with the specific concerns of forest cover data,
further testing to better define the accuracy levels and thresholds required for operational use,
identification of the steps necessary to move the semi-automated approach into an operational mode.

The highest priority activity is establishing an operational environment for the semi-automated approach. Re-evaluation of current project priorities is currently underway to establish proper justification for a commitment to this activity. The identification of an ongoing support project for this application is expected for the next fiscal year.

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GIS and Computer Video-imaging in Forest Landscape Management

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Abstract
Techniques which accurately and realistically simulate proposed alterations are now being used along with GIS to design cutblocks so that visual impact is minimized and harvesting values are retained, and to inform the public so the impacts of cutting can be perceived before any alteration has taken place. A GIS with digital terrain modelling capabilities provides the accuracy, and computer video-imaging is used in conjunction for a realistic representation. The examples shown are modified photographs which simulate the landscape at future points in time, showing the sequence of cutting, green-up and reforestation. The way these simulations are being used in forest management is explained.

Introduction

As recreation and tourism become increasingly important to the economy of British Columbia, and as environmental quality becomes an ever greater issue, more attention is being directed to the scenic values of the landscape. The newspapers regularly include stories about public efforts to block logging activities, and the resultant delays, court cases and generally negative sentiments which follow.

The Ministry of Forests (the Ministry) has been examining the visual impacts of logging, and incorporating measures to harmonize those impacts for some time. The Forest Landscape Handbook (1981) and the subsequent policy on landscape management (1982) are used in the Ministry's program to implement landscape management concepts and techniques throughout the province.

The Ministry has its own staff of landscape foresters who conduct visual inventories and provide input to forest companies on their proposed harvesting plans. Forest companies are also being encouraged to take on the responsibility of some of this work. As the public becomes more concerned and more active in promoting their causes, the demands for visual landscape management are increasing. Neither forest companies nor the Ministry can afford the expenses involved in confrontations.

New technologies which can assist in the design of cutblocks and the public involvement process have been progressing rapidly in recent years. This paper documents the primary techniques for visual simulations which are available for use on microcomputers, and illustrates one state-of-the-art application.

Previous Technologies and their Applications

DTM and GIS Programs

The early computer programs for visual landscape management operated on main-frame computers. Two of the key historic programs were VIEWIT (1975), which had the ability to compute the areas seen from a particular point, and to calculate slope and aspect. Output was available only in plan form, as symbols produced on a black-and-white printer. The second, PERSPECTIVE PLOT (1980), was much more graphic in its representations. It could draw fishnet-line perspective sketches which were accurate, and it could also overlay, in perspective form, trees, outlines of proposed cutblocks, and other features. These graphic sketches could be used directly for analyzing or obtaining input on proposals, or they were sometimes used as the base for artist's representations.

Micro-computers now have the same capabilities in digital terrain modelling (DTM). Using contours, which are digitized directly from hard copy maps or obtained through maps already in digital form, the software calculates a grid of x-y coordinates, and links those to elevations or z values. The greatest capabilities result from the integration of DTM programs with complete GIS systems. This can allow for applications such as:

- mapping of visible areas from a viewpoint,
- overlaying several visible area plots to determine how many times land areas are seen from a series of points, such as viewpoints along a road corridor,
- drawing perspective sketches of the views from particular points,
- superimposing planimetric information, such as roads, rivers, and cutblock boundaries, on perspective sketches,
- colouring perspectives according to thematic maps, e.g., land cover so that forested portions of the view would be green, and alpine areas yellow,
- drawing symbols onto perspectives to scale, e.g., trees of a given height.

There are a number of advantages to these applications of GIS/DTM systems. They produce relatively accurate simulations (this being somewhat software-dependent), and they allow for flexibility in analysis. For example, maps could be produced showing: the number of mountain peaks visible from all parts of a valley, the relationship between visible areas and proposed cutblocks, the impacts of a proposed forest plan on recreation resources, or the quantities of high-value timber within proposed cutblocks which are visible from a road corridor.

The primary disadvantage of these systems for visual landscape management is that simulations are not very realistic. While they represent a huge improvement over attempts to visualize proposals from two-dimensional maps alone, the line drawings are difficult for some people to comprehend in terms of their real implications.

Computer Video-Imaging

Another type of technology called computer video-imaging has recently become available for use in simulations. The software for this tool is very similar to 'paint' programs which allow for graphic generation and manipulation of images. A special hardware graphics card inserted into the computer enables the input of a video or photographic image. This means that a photograph of a landscape could be brought up on a computer monitor and manipulated to show proposed alterations.

The advantages of this technology are the flexibility in graphic manipulation and the realism. Since parts of an image can be moved, or different images can be 'cut and pasted' together, a proposed clearcut could look exactly like one, and output could be produced in video, as a slide or as a photographic print.

The primary disadvantage of this type of system used alone or with inappropriate additional software is the lack of accuracy. Simulations could be produced by eye or using CAD software (which is not intended for modelling terrain), resulting in images which look extremely realistic but bear no resemblance to the alteration actually being proposed. This can be extremely misleading to those who may not understand how an image was produced.

Integration of Computer GIS/DTM and Video-Imaging
The greatest power in these tools for landscape management is derived from their integration. Software is available which can allow a DTM perspective complete with proposed cutblock boundaries to be 'captured' and superimposed on a photograph input into the computer through a video camera.

The primary challenge using this technique is achieving accuracy in lining up the photograph and the DTM image. It is necessary to know precisely where the photographer was standing, the (compass) angle of view, the angle of the camera with the horizon, and the lens focal length (e.g., 28 mm wide angle or 50 mm standard lens). Unless the DTM perspective and the photograph can be registered to each other precisely, the simulation will not be accurate. It is also important that the tree height be considered, and the illustration of trees at their known height around the cutblock perimeter will add to the accuracy of the simulation.

Once the photograph and the perspective are lined up, the next step is to simulate the proposal. In the examples shown here, the simulated portions of the scene were taken from other photographs. For example, to show a clearcut, a photograph of a clearcut from a similar distance on a similar slope taken on a day with equivalent light conditions would be used. Portions of the clearcut 'library' photograph would be extracted and molded to fit the proposed cutblock boundaries on the DTM line drawing. The area along the horizon is dropped down by the height of the trees showing along the horizon. The final step is to refine the edges. Blending is usually used to simulate atmospheric blur, and the foreground edge needs to be modified so that trees or other objects in front of the clearcut are not cut off. For example, the top of a tree which, from the viewer position, extends into the clearcut is replaced by inserting the one back from the original photograph.

Simulating regeneration is more difficult than the simulation of cutblocks. With regeneration, the type of forest in the library photograph also should be similar to the forest in the original scene. The differences between regeneration and original forest can be extremely subtle, and the subtleties are challenging to portray.

Examples
Figure 1 shows a landscape for which there is a forest cutting proposal. Figure 2 shows a computer-generated perspective superimposed on the scene. The darker lines of the perspective indicate the locations of proposed cutblocks, and the graphic tree symbols indicate existing tree height around the cutblock boundaries. Figure 3 shows the upper cutblock simulated as a clearcut. Figure 4 shows that area greening up, and a clearcut in the lower cutblock. Figure 5 illustrates both cutblocks greening up. One more example of a different scene, Figure 6 shows a simulated clearcut in the lower left corner and the manner in which the hydro poles and treetops can be replaced so that they still appear in front of the clearcut.

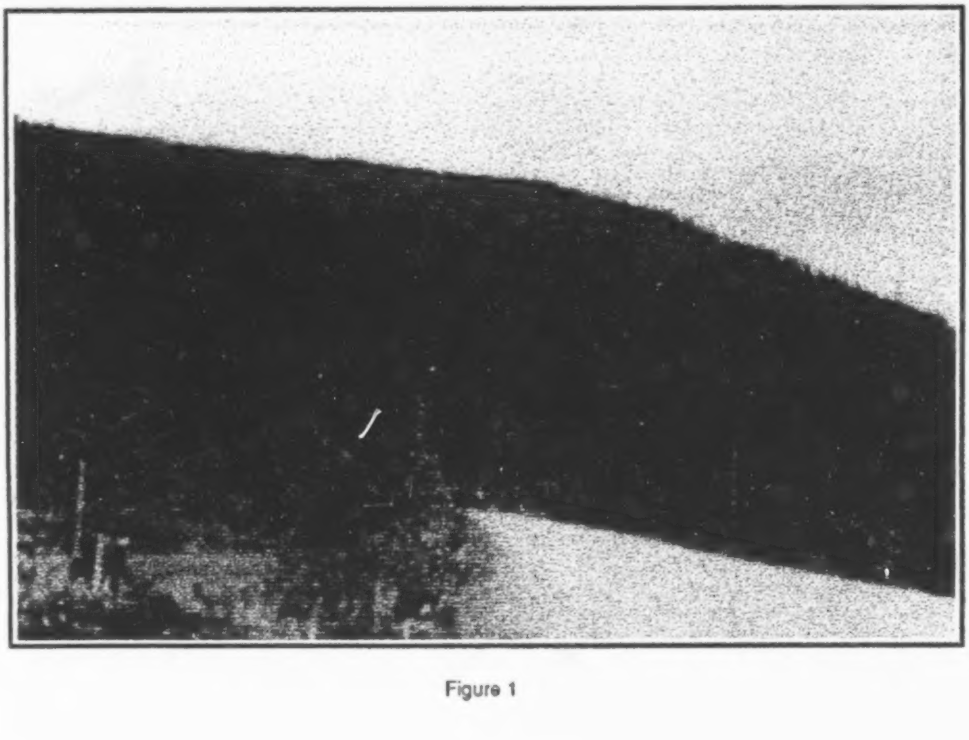

Figure 1

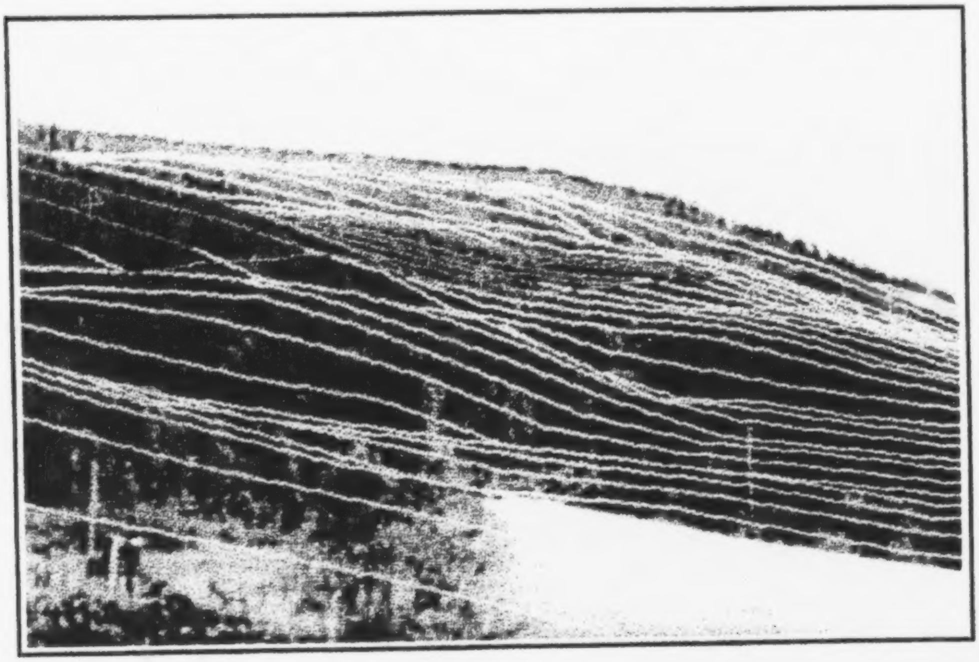

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Applications

The technology shown is useful in forest landscape management in a number of ways. Firstly, it is used to modify and improve the design of cutblocks. Through seeing what the proposal looks like, landscape foresters have the ability to try alternative designs and to see the impacts directly. For example, if the lines of a cutblock design look too rectilinear when simulated on the photograph, the boundary of the block can be refined until the simulation shows an improved result. Another modification might be the timing of cutting. If a scene in which three proposed cutblocks are visible looks too modified with cutting occurring close to the same time, the timing of cutting can be adjusted and the alternative illustrated through the simulations. The second application is public involvement. The public is demanding more and more involvement in decisions which affect the landscape and the environment. The ability to show simulations like this which are accurate and realistic can greatly enhance that process. In some cases, the simulations can allay fears of proposed alterations having more visual impact than actually would occur. In other situations, the public might be able to suggest design alternatives which are acceptable to them and also to the forest companies.

The Future

It is easy to imagine some of the technologies which will follow this one. Soon, the ability to have the modified perspective image transferred back to the GIS plan will simplify the process of generating improved alternatives, which now must be done through trial and error.

The resolution of imaging systems is already improving, and costs for higher resolution systems will continue to decrease. The future is encouraging, as these technologies will allow for better design tools, a more educated public, and ultimately, improved decision-making about our productive and fragile resources.

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Managing Resource Conflict

Session A3
GIS for Agricultural Planning

Using Microcomputer-based GIS and Image Analysis Systems in Farm Management

Determination of Land Suitability for Dry Farming Agricultural System - a case study from Iraq

Potential Applications of GIS Technology in Indonesia

Development of New Technologies for Resource Evaluation and Development; An Electronic Atlas for Tajikistan

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Using Microcomputer-based GIS and Image Analysis Systems in Farm Management

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Abstract
Microcomputer-based geographic information systems combined with image analysis are proving to be excellent tools to improve agricultural field management. Crop yields and crop quality are influenced by climate, water balance, soil physical properties and nutrient conditions. In intensive farm management, the farmer aims at a uniformly high quality and quantity of crop by minimizing the spatial variability. A digital database is thus essential and can significantly improve the efficiency of farm management. The application of variable rates of fertilizers in accordance with the soil variability, selective irrigation, and harvesting of forage crops according to crop quality are obvious examples of this practice. Data from dairy farms were used to show that selective forage yield classes can be predicted from the quantitative evaluation of color infra-red imagery. Good relationships were also found between pixel values, corresponding soil conditions, site variables and crop quality parameters such as crude protein and foliar phosphorus contents. Combining imagery and biophysical databases into a GIS system will allow one to model crop production and develop management scenarios on an economic basis. A farm based GIS system can significantly improve field management techniques and provide a basis for economic accounting on a field by field basis over time.

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Determination of Land Suitability for the Dry Farming Agricultural System in Iraq Using Computer Assisted GIS Analysis

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Abstract

Extensive tracts of land in northern Iraq suffer from drought but could be utilized with the Dry Farming Agricultural System, which would offer agricultural crops to feed the country and its neighbours. This study was conducted to determine the suitability of the land for the Dry Farming Agriculture System and to determine the ability of GIS to handle efficiently and rapidly these location and suitability problems.

The results show GIS suitability analyses can determine the appropriate areas for the dry farming system. GIS is very efficient in handling this problem, and the results are reliable enough to back the managerial decisions, with obvious savings of time, money, and human efforts.

Introduction

With the increasing demand on food and fiber due to the worldwide population explosion, sufficient and effective use of agricultural resources are needed. The problem of the lack of water, especially in the arid and semi-arid zones, where there are good soils, has forced people throughout history to utilize any water available for agricultural purposes.

Drought in agricultural terminology means a lack of sufficient rainfall for plants to survive. Dry land is land where the amount of evapo-transpiration is more than the amount of rainfall. Therefore, the Dry Farming Agriculture System (DFAS) is a system that is used where water is the only factor that controls the growth and productivity of agricultural crops. It includes agricultural operations that ensure utilization of any limited amount of water available and deals with the agricultural crops which have the ability to grow with this limited amount of water. Dry Farming Agriculture Systems have been used around the world wherever dry conditions prevail. There are several indirect variables that affect water availability such as the monthly rainfall average during the growing season, soil permeability, temperature (maximum & minimum) during the critical growing period, topographic levels, humidity, and evapo-transpiration.

Extensive tracts of land in the northern part of Iraq suffer from drought but could utilize the Dry Farming System to offer agricultural crops food to the country and as export to its neighbours.

A GIS designed to process spatial data for mapping, statistical and land management purposes.
The objectives of this study were :

- To determine the suitability of the land for the Dry Farming Agriculture System,
- To compare the best locations found by the GIS with the existing ones,
- To determine the area of land which is suitable for this system and compare it to the area of land that is used currently,
- To determine the ability of GIS to solve efficiently and rapidly the location and suitability problems.

Materials and Methods

Study Area

Iraq is in the southern part of the North Temperate Zone between latitudes 29° 5' & 37° 25' and longitudes 38° 45' & 45° 48'. Roughly the size of California, it has an area of 175 000 square miles. Iraq is bounded on the north by Turkey, on the west Syria and Jordan, on the south by Saudi Arabia, Kuwait and the Arabian Gulf and on the east by Iran. The country can be divided roughly into four regions: the mountainous snow-clad north and north-east, about 20% of the country; a central plateau, mostly limestone, representing 59.5% of the whole; the southern lowland alluvial plain, with many lakes, swamps, and marshes; and the western desert. Two rivers, the Tigris and the Euphrates, traverse the country from north to south from their sources in the uplands of Turkey. They meet in the Shatt-Al-Arab, which runs through the Basrah Governorate to the Arabian Gulf. The Tigris is 1 718 km long, of which 1 418 km are in Iraq. The Euphraties is 2 300 km long, of which 1 213 km are in Iraq. The Shatt-Al-Arab, from their confluence to the Arabian Gulf, is 110 km long. Summer in Iraq is generally hot and dry and temperatures of 100 F° are common. Winter may be surprisingly cold and frosty in Basrah, and very severe in the north. December to March are the wettest months of the year. The average rainfall in Baghdad is 5.5 inches, Basrah 1.5 inches, and in Mosul 7.5 inches. Figure 1 shows the location map of the study area.

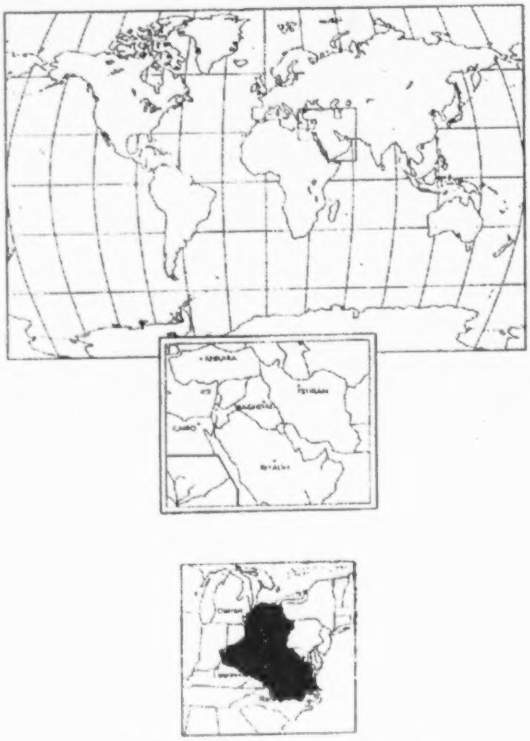


Figure 1. Location Map of Iraq and a Size Comparison to the United States

Data Required

1. Basic map adopted from George Westermann map of the Middle East & India.
2. Water map, which includes all the surface water features.
3. Transportation map, which includes all types of highways and railways.
4. Soils map.
5. Urban area map, which includes the Capital, Baghdad and other major cities.
6. Precipitation map, which includes the average seasonal precipitation and the growing season precipitation (Feb. - April).
7. Evaporation map, which includes average seasonal evaporation and the growing season evaporation.
8. Temperature map, which includes the average seasonal minimum and maximum temperatures during the growing season.

9. Humidity map, which includes the average growing season humidity.
10. Topographic map.
11. Landuse map, which include all classes of landuse.
12. Tables of temperature, evaporation, humidity, and precipitation for the regions of Iraq.
13. Tables of agricultural land productivity for winter wheat and barley in northern Iraq.

Created Maps

Temperature and humidity maps were not available for this study. Therefore, these were created using the available temperature and humidity tables for mid- and northern Iraq. The available numbers were used as point data which were then, through interpolation techniques, used to create the missing information between the known sites.

Data Input

ERDAS software and hardware were used for digitizing the input data in paper form. The hand digitized data consisted of basic topography, water, transportation, soils, urban areas, precipitation, evaporation, and landuse maps. The basic topography, water, and transportation map was taken from the George Westermann map (1968) of the Middle East & India. The soils map was digitized from Al-Ani (1980), it represents the greatest soil group classification reflecting American soil classification concepts. The urban map was digitized from the Iraq Tourist Guide. Precipitation and evaporation maps have been adopted from Alfakhry (1979). The landuse map was adopted from Youkhana (1978) and the George Westerman map. After digitization, each data layer was gridded within ERDAS to a 2x2 km cell size, providing a cell resolution of 4 sq. km. Each gridded layer of data was registered and made coincident within ERDAS.

General Approach

The general approach considered in the site selection GIS analysis for this study was as follow:

1. Exclude all transportation systems, surface water features, and urban features from the study area since these areas will be excluded from the agricultural land use. Model 1 in Figure 2 represents this process.

2. Select the most suitable soil type for the dry farming agricultural system. The agricultural crops which are grown in the area using the dry farming system are winter wheat and barley, and according to Alfakhry (1979) and Al-Ani (1980), the desert soil groups are undeveloped soils with very poor drainage and very high percentage of salt, which make them unsuitable for growing these crops. Moreover, the mountain soil groups are currently under forest cover. Therefore, these two soil groups are excluded from the soils map because they are not suitable or available for the dry farming agriculture system.

3. Select the areas that have the most suitable weather conditions (i.e. precipitation, evaporation, humidity, and temperature). To determine the most suitable weather conditions, four maps were used along with the runoff map, which was derived from the precipitation map. The amount of the runoff has been measured for the area as 25% - 35%. The following model was used to find the water intake by the soil which can represents the soil permeability or the water that the soil retains after subtracting evapo-transpiration.

Water Intake = Precipitation - (Runoff + Evapo-transpiration)

The result of this formula is compared with the minimum needs of the plants for water. If the amount is ≥ 150mm, then it will be suitable. This comparison will represent the major factor in the weather conditions suitability. However, there are two other factors which have to be taken in to account: temperature and humidity. The critical temperature is approximately 23° C; if the temperature is ≤ 23° C, it is suitable. The critical humidity percentage is between 50% to 60%; if the humidity is ≥ 50 - 60%, crops will prosper. These relationships are shown in Model 2 in Figure 3.

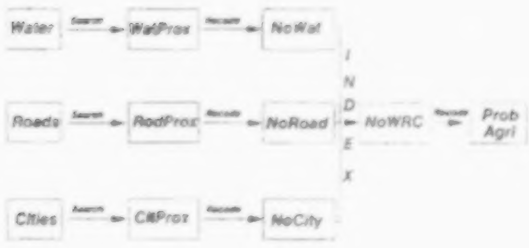


Figure 2. Avioding Roads, Water Surfaces & Urban Areas, Model 1

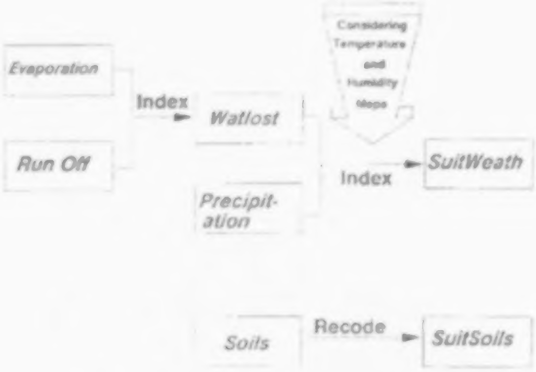


Figure 3. Weather & Soils Suitability, Model 2

4. Add the most suitable soil to the most suitable weather to the ProbAgri (land area after deleting roads, surface waters and urban features). The result is the final suitability map which has a list of land classes. The class with the highest value will be the most suitable area and as the value of the classes decreases, the suitability of this area for the dry farming system will decrease. This procedure is shown by Model 3 in Figure 4.

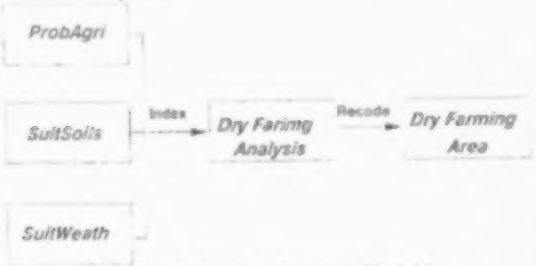


Figure 4. Dry Farming Area, Model 3

5. Measure the potential site area.

6. Compare the new sites selected by the study with the existing ones by area and by cross-tabulation techniques between the potential dry farming map and the base map and between the current landuse map and the base map to arrive at the area of both current use for this system and the potential area that could be used, as suggested by this analysis.The cross-tab between the potential dry farming map and the current landuse map will show the extension and the coverage of the potential new areas suitable for dry farming system on the landuse classes that are currently used (i.e., grazing and irrigated agriculture land classes), as shown by Model 4 in Figure 5.

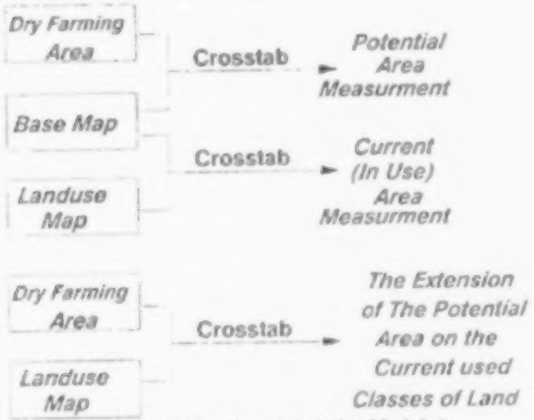

Dry Farming Area
Base Map
Landuse Map
Crosstab
Potential Area Measurment
Crosstab
Current (In Use) Area Measurment
Dry Farming Area
Landuse Map
Crosstab
The Extension of The Potential Area on the Current used Classes of Land

Figure 5. The Crosstabulation Model 4

Results and Discussion

Figures 2, 3, 4, and 5 show the flow charts of the analysis and the results (e.g., maps) which were derived. The flow charts show four models: The first model, in which all the water, transportation and urban features were deleted because they cannot be used for agricultural purposes; the second model, which includes the areas that are suitable with respect to two important variables, the weather and the soil type; the third model combines the most suitable features from the above two models to come up with the most suitable area taking into account all control variables; the fourth model is derived from cross-tabulations between the base map and the potential dry farming map, between the base map and the current landuse classification map, and between the potential dry farming map and the current landuse map. Figure 6 shows the dry farming suitability analysis map as a results of Model 3. Figure 7 shows the potential dry farming area suggested by this analysis and by an improved version of Model 3. Figure 8 shows the current landuse map of the country and the area that is currently used for the dry farming system.

There are two methods of comparison between the current dry farming areas and the potential areas suggested by the GIS analysis: first, the qualitative method which suggests a visual comparison between the two areas and notes how far the potential areas are extended; the second,the quantitative method compares the areas of the two sites.

From the qualitative comparison, it is very clear that the potential areas were extensions of the original areas of dry farming; they extended mostly into the grazing landuse class and partially into the irrigated agricultural lands. Since the grazing season is very short in Iraq, running from the end of March or beginning of April to mid-May, it might be more useful if part of the grazing lands were utilized for dry farming. While the extension of the potential areas covers a small part of the irrigated agricultural lands around the Tigris river, it may be possible to impose the new system there because the irrigated area is relatively small compared to the encroachment on the grazing lands.

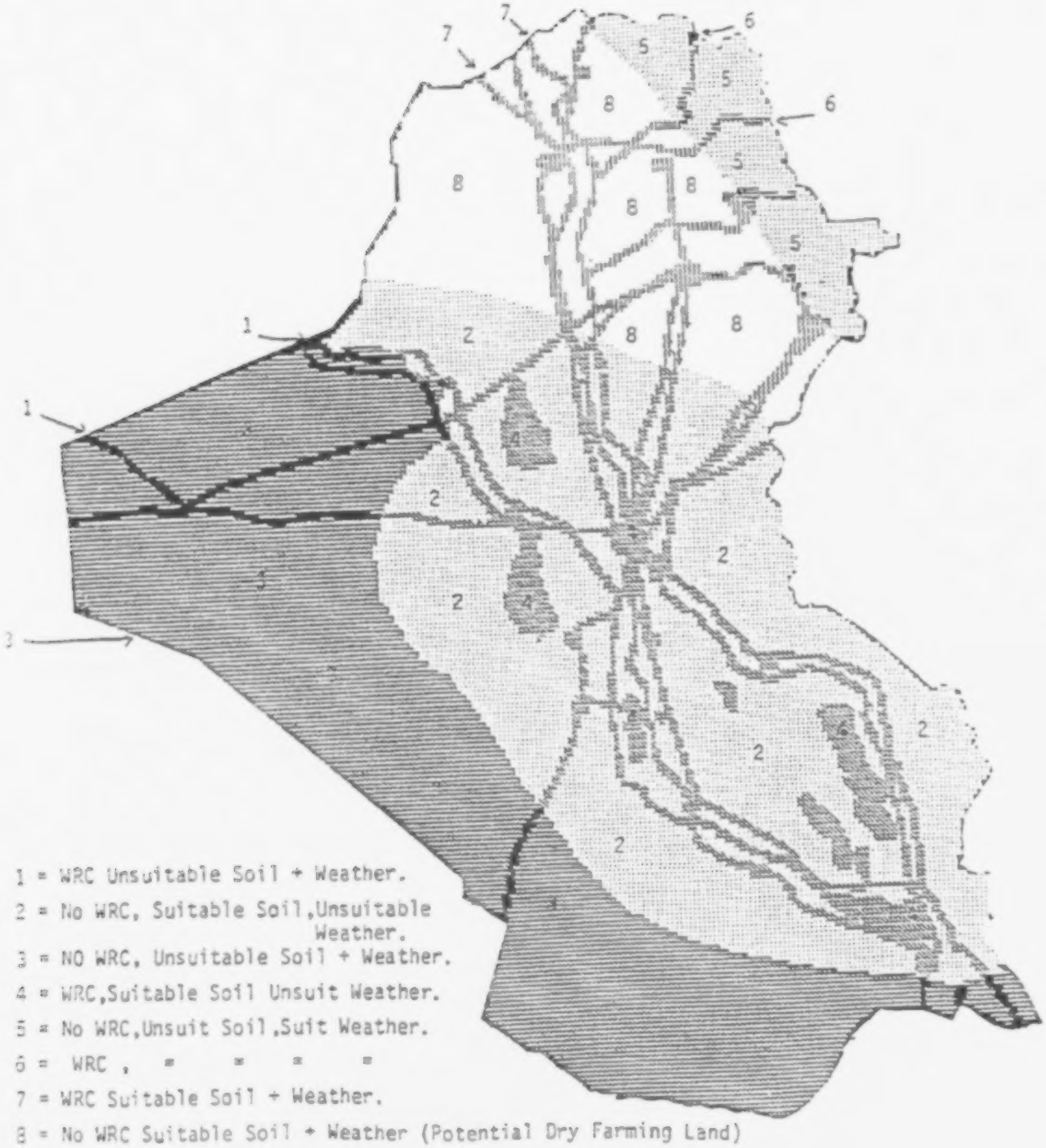
From the quantitative comparison, it is shown that:

1. The area currently used in dry farming system is 25 276 sq. km,
2. The potential area that could be used for this system is 59 784 sq. km,
3. The potential area extends over 18 400 sq. km of the grazing lands,
4. The potential area extends over 2 312 sq. km of the irrigated agricultural lands.

It is clear that the potential area that can be used in this system is more than twice the currently used area. The areas in 3 and 4 above are consistent with the qualitative comparison.

Conclusions

- This study supports the contention that using GIS analysis to find the best locations for the dry farming agriculture system is feasible.
- GIS analyses identify efficiently and quickly the locations and suitability of land for the dry farming agriculture system.
- Further analyses are needed, as detailed information becomes available for elevation, to study the effect of slope and aspect, as derived layers from the elevation data, on the results of this study.
- All the objectives of this study were reached.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1 = WRC Unsuitable Soil + Weather.
2 = No WRC, Suitable Soil,Unsuitable Weather.
3 = NO WRC, Unsuitable Soil + Weather.
4 = WRC,Suitable Soil Unsuit Weather.
5 = No WRC,Unsuit Soil,Suit Weather.
6 = WRC , " " " "
7 = WRC Suitable Soil + Weather.
8 = No WRC Suitable Soil + Weather (Potential Dry Farming Land)

Figure 6. The Dry Farming Suitability Analysis Map

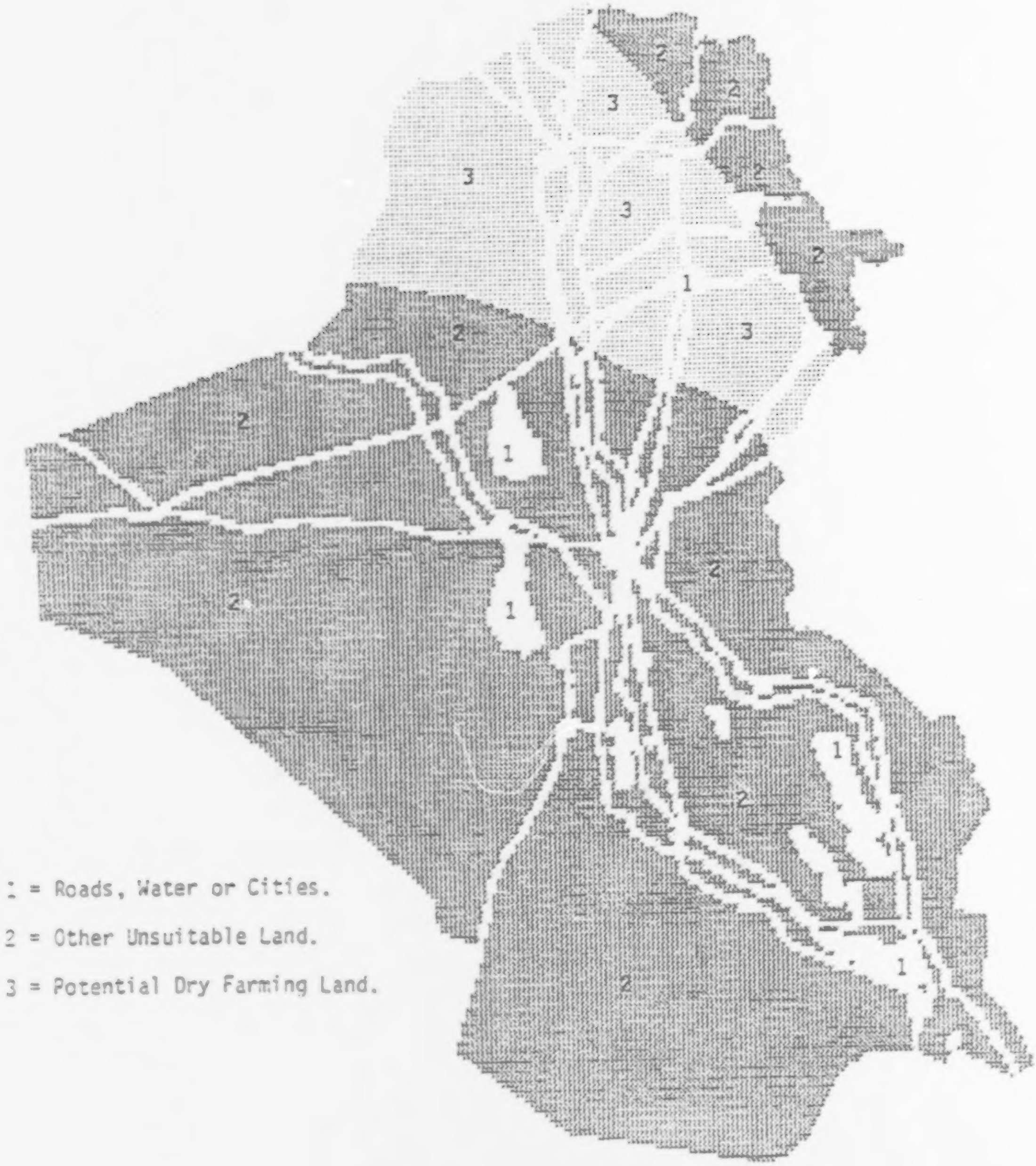
1 = Roads, Water or Cities.
2 = Other Unsuitable Land.
3 = Potential Dry Farming Land.

Figure 7. The Potential Dry Farming Land Map

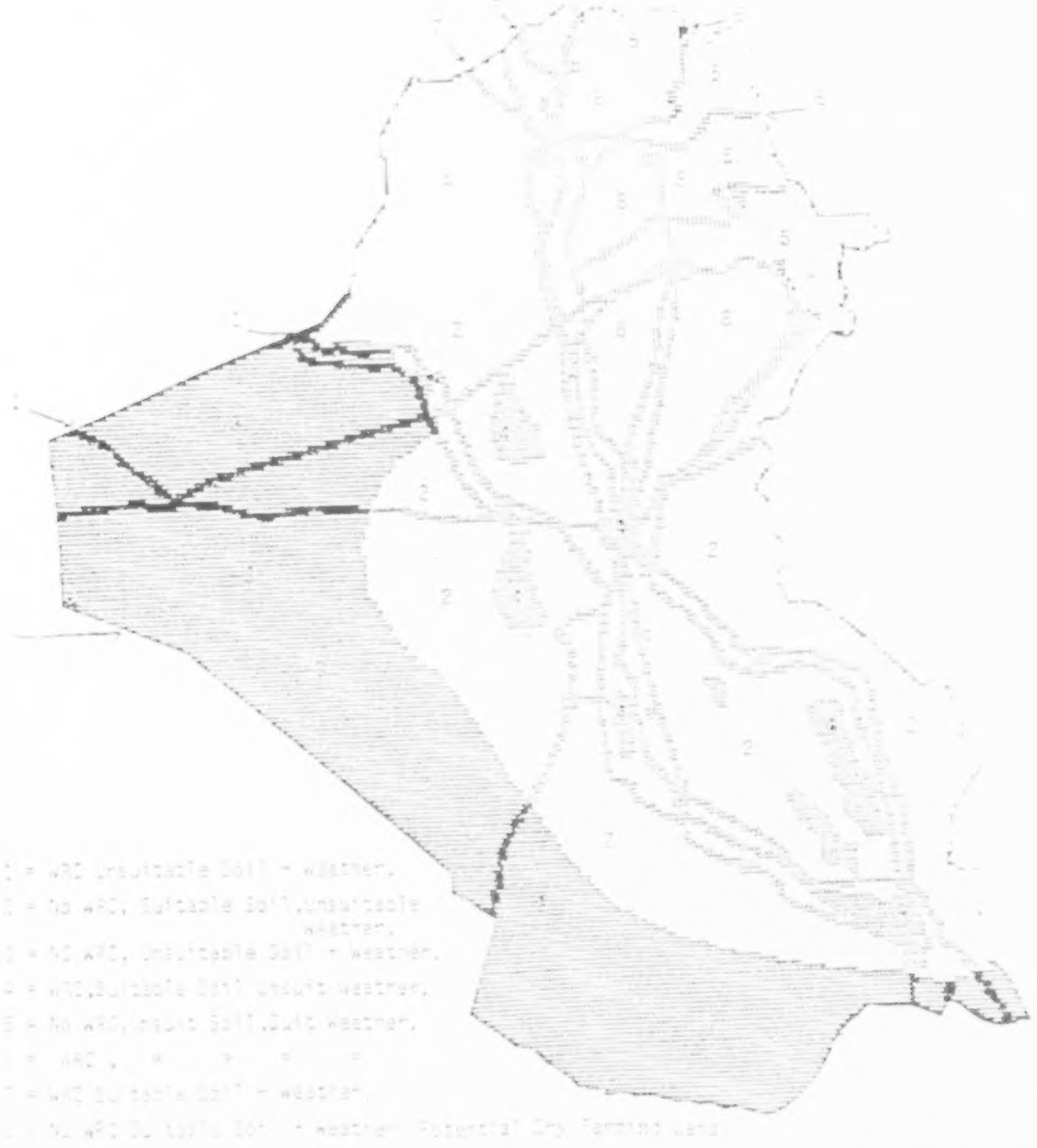
1 = WRC Unsuitable Soil + Weather.
2 = No WRC, Suitable Soil, Unsuitable Weather.
3 = No WRC, Unsuitable Soil + Weather.
4 = WRC, Suitable Soil Unsuit Weather.
5 = No WRC, Unsuit Soil, Suit Weather.
6 = WRC , " " " "
7 = WRC Suitable Soil + Weather.
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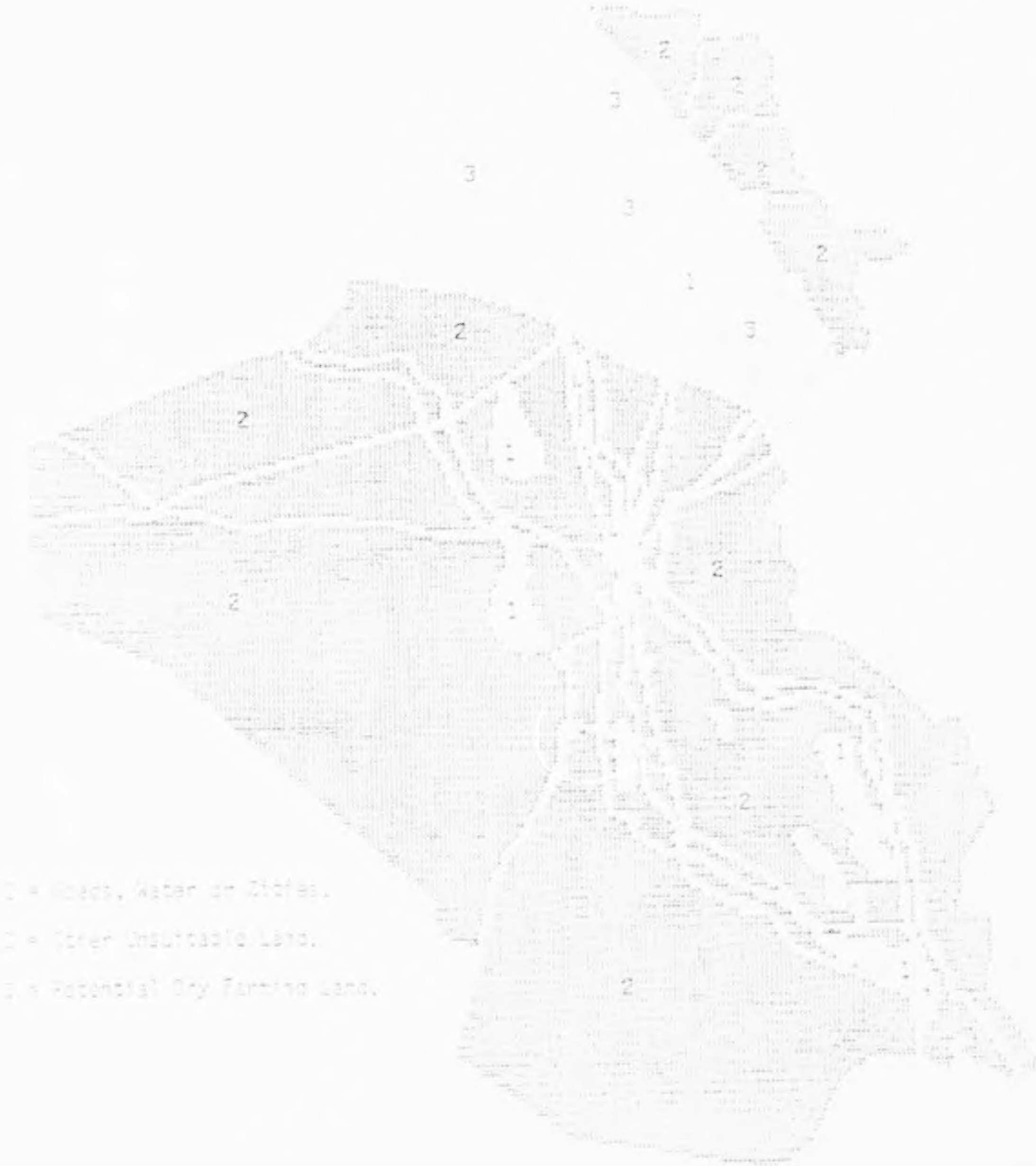
Figure 6 The Dry Farming Suitability Analysis Map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1 = Roads, Water or Cities.
2 = Other Unsuitable Land.
3 = Potential Dry Farming Land.

Figure 7. The Potential Dry Farming Land Map

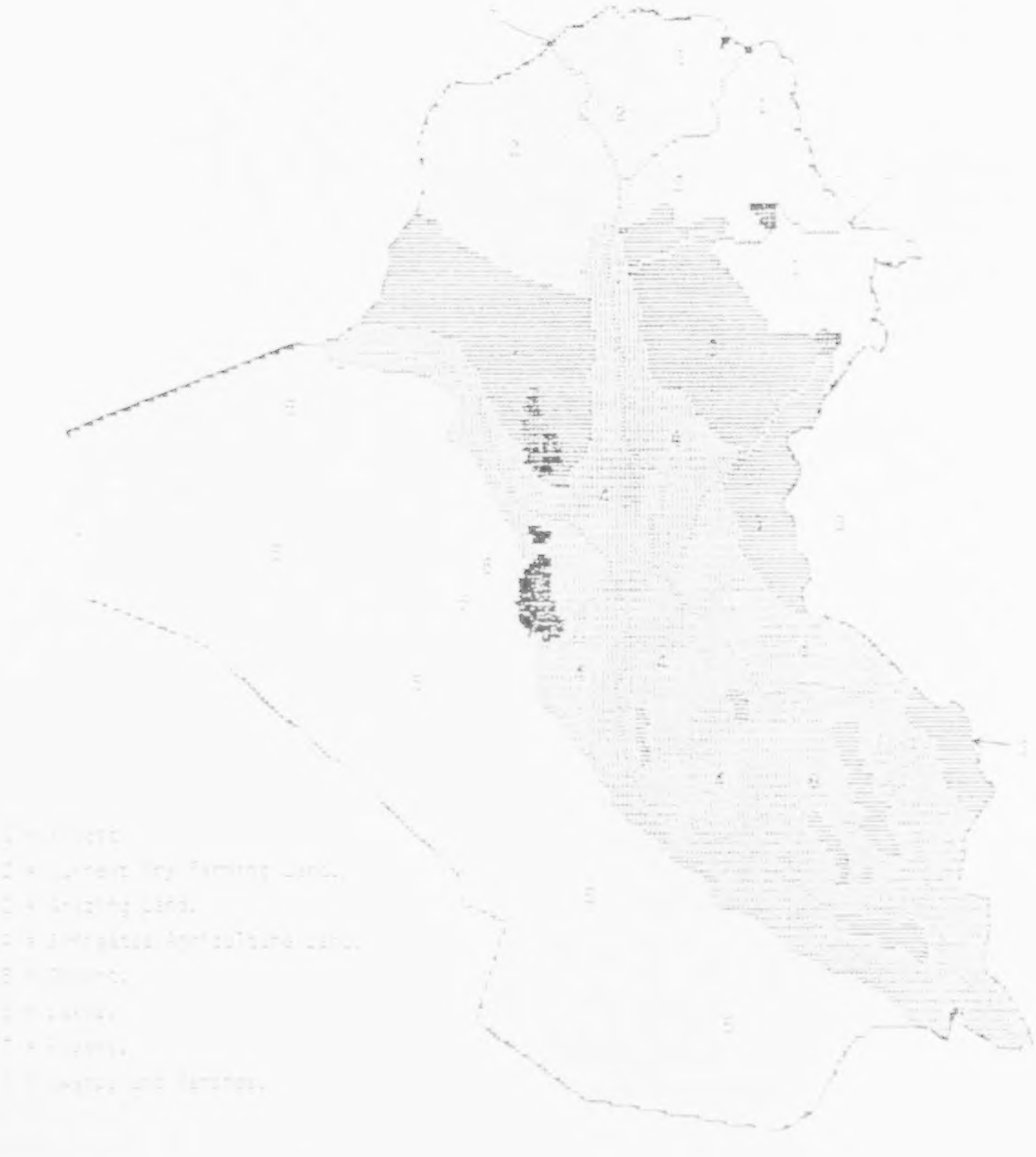
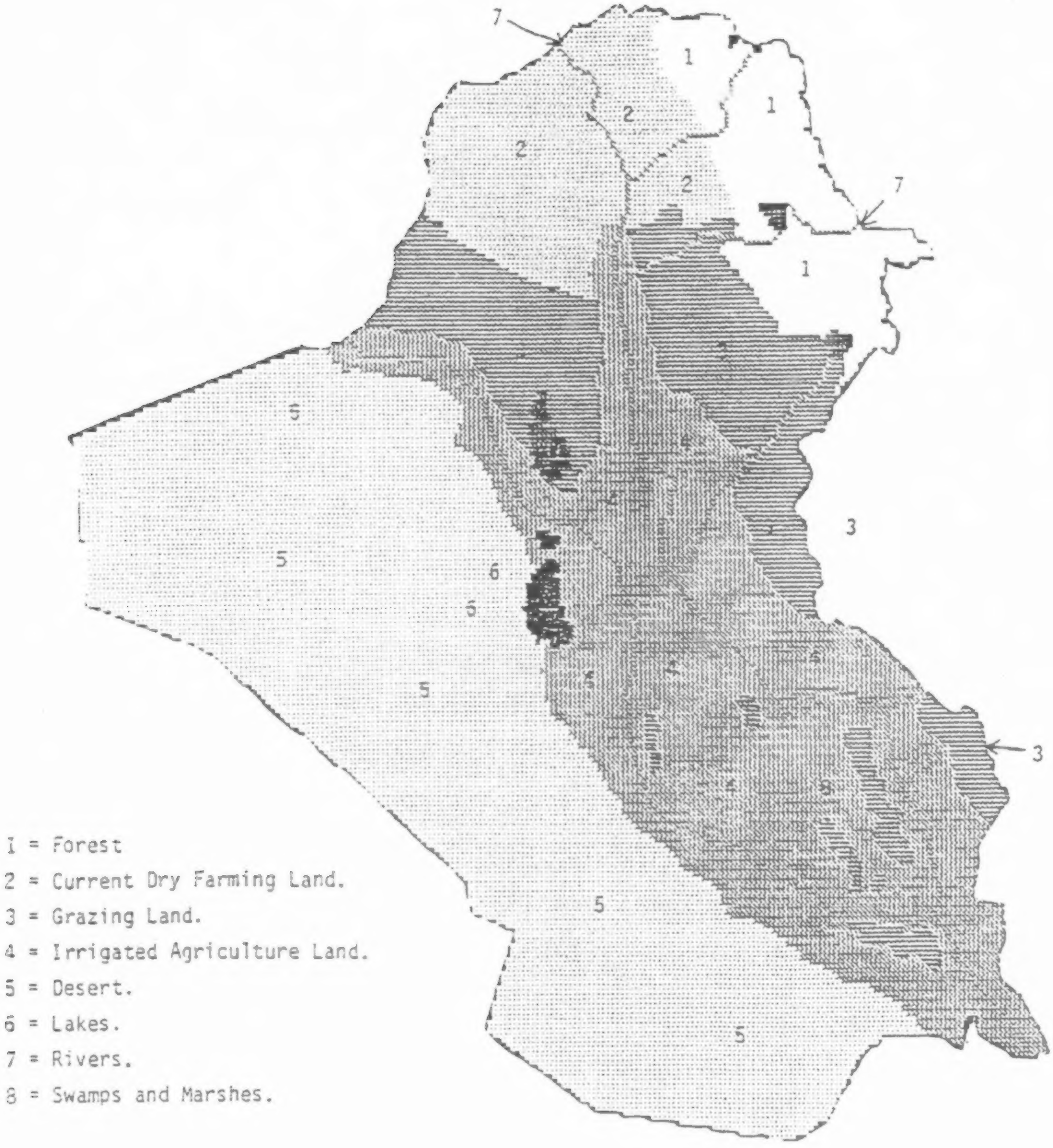

1 = Forests.
2 = Current Dry Farming Land.
3 = Grazing Land.
4 = Irrigated Agriculture Land.
5 = Desert.
6 = Lakes.
7 = Towns.
8 = Swamps and Marshes.

Figure 6: The Current Landuse Map (General)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1 = Forest
2 = Current Dry Farming Land.
3 = Grazing Land.
4 = Irrigated Agriculture Land.
5 = Desert.
6 = Lakes.
7 = Rivers.
8 = Swamps and Marshes.

Figure 8. The Current Landusr Map (General)

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GIS'90 Symposium

Vancouver, British Columbia
March 1990

Potential Applications of GIS Technology in Indonesia

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Abstract
Shifting cultivation (slash and burn agriculture) is a major concern to the Indonesian government. The government does not know how many communities exist or their location. The 200-person communities clear, burn and abandon 100 ha sites after three years' use. This practice is destroying the forest land base at an alarming rate. The agriculture sites are openings within the forest which can be detected from conventional and space-borne imagery. GIS systems have been supplied to the Indonesian government and can be used in conjunction with remotely sensed data to map existing sites and to update settlement movement.

Indonesia is currently being mapped using 1:250 000 Landsat paper prints. Five years have been spent in producing a preliminary base map. Image interpretation is done visually and mapping is done by hand. Image quality is poor and only two map classes can be delineated with any consistency. Image analysis combined with GIS would speed the mapping process and in all probability increase the number of map classes.

The currently used ILWIS GIS is capable of integrating and overlaying remote sensing image analysis data with GIS data from digital map input. The potential application using ILWIS in relation to shifting cultivation monitoring and land use change mapping will be presented.

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Development of New Techniques for Resource Evaluation and Development: An Electronic Atlas for Tajikistan

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Abstract
The state of GIS and automatic mapping in the USSR has advanced to the point where the necessary infrastructure and methodology exist to initiate a major Geo-Information project in the Tajikistan SSR. This is to serve as a model of resource evaluation for other Socialist Republics and is to examine scenarios for environmental, population, and economic development of Tajikistan for the 21st century. Tajikistan, with an area of 150 000 square miles and 5 million people and a population growth of 3.5%, reflects the whole spectrum of development problems found in mountainous areas of Central Asia. There is a highland-lowland polarization, there are environmental problems relating to deforestation, overgrazing, reduction in biodiversity and there are contradictions in development and economic-ecological conflicts. An electronic atlas of resources and resource scenarios is to be produced using sequential analysis, climatic and landscape models, theories of games and expert systems.

The project is planned under the auspices of MAB Unesco, the UN University, and enjoys Swiss and US assistance. The goals for the first phase of the project are to formulate the hardware and software requirements for the Geo-database, to create an inventory of resource data, to develop the conceptual models for the atlas and to develop scenarios.

Managing Resource Conflict

Session A4
GIS for Park and Recreation Management

Sensitivity Zonation for Forest Road Construction Sensitive Areas

Monitoring the Impact of Off-Road Vehicles

Using a GIS for Prescribed Fire Management at Cuyamaca Rancho State Park, California

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Sensitivity Zonation for Forest Road Construction

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Abstract

The Forest Service of the Austrian province of Styria has recently implemented the use of a geographic information system and is now using it in several projects, one of which is described in this paper.

In this project, the functions of the GIS are used in order to overlay different levels of environmentally-relevant information.The aim is to define which areas of the mountainous regions of Styria are suitable for further accession by forest roads and which are to be excluded from any human influence and preserved as objects of study for the development of natural woods. With the GIS it is possible to define which policy will be applied in which area.

The Environmental Information System of Styria (Landes-Umwelt-Informations-System - LUIS)

In 1986, the government of the province of Styria decided to establish an environmental information system called LUIS (Landes-Umwelt-Informations-System. (German for 'province-wide environmental information system'), for the collection and storage of environmentally-relevant information to serve as a data base for regional planning and other political decisions.

Decentralisation is one of the main ideas of this system. The different administration departments are assigned to individually collect, store and manage and prepare their data for further use by other departments. Data from the individual departments are then entered into LUIS, overlaid and used in interdisciplinary regional planning. On the other hand, each department is free to use these sets of overlaid data or information from other departments, which should reduce the redundancy of data within the province's administration. (Bogner W., 1989)

An important decision in the management of geographic or spatial data is the chosen input scale. In Styria, it is the 1:50 000 scale, which is used as a standard for province-wide planning and data display. One reason is that this scale is also used for nationwide cartography and therefore a large amount of topological information already exists in this scale.

The ARC/INFO geographic information system is used to store and manage environmental information within LUIS, and interfaces for database management systems like ORACLE or DBASE have been installed in order to use existing datasets without having to re-enter them manually.

The configuration of hard- and software is displayed in Figure 1 below:

As most of the decisions within the forest sector are directly related to clearly defined areas, the forest department soon realized the importance and necessity of employing the geographic information system for its purposes. On the other hand, maps and spatially related statistics have always been used by the forest department and so there is a large amount of data which, once it is entered into the system, will be of great use for other departments.

The project 'Sensitive Areas in Forest Road Construction' served as a test for the capabilities of the GIS as well as for the use of information from different sources.

Description of the Conflict

In Austria, as almost everywhere in middle Europe, forestry nowadays is becoming an object of public interest, especially for environmental groups and scientists, who are concerned about the possible negative impacts which forest management might cause to nature.

Because of the rather dense settlement in the Alpine countries, there are only a very few areas which have not been subject to human influence. And even valleys, which do seem untouched today, were clearcut in former days in order to gain wood for ironworks or salt mines so that they cannot be seen now as natural ecosystems.

Within the last decade, the improvements in technology have enabled foresters to access even remote regions by forest roads, in order to start regular management.

In mountainous regions, the protectional value of forests has always been of great importance and is steadily increasing, as expanding settlement and tourism especially depend on it. So in addition to rentability of forest management, the reliability of the forest's protectional functions

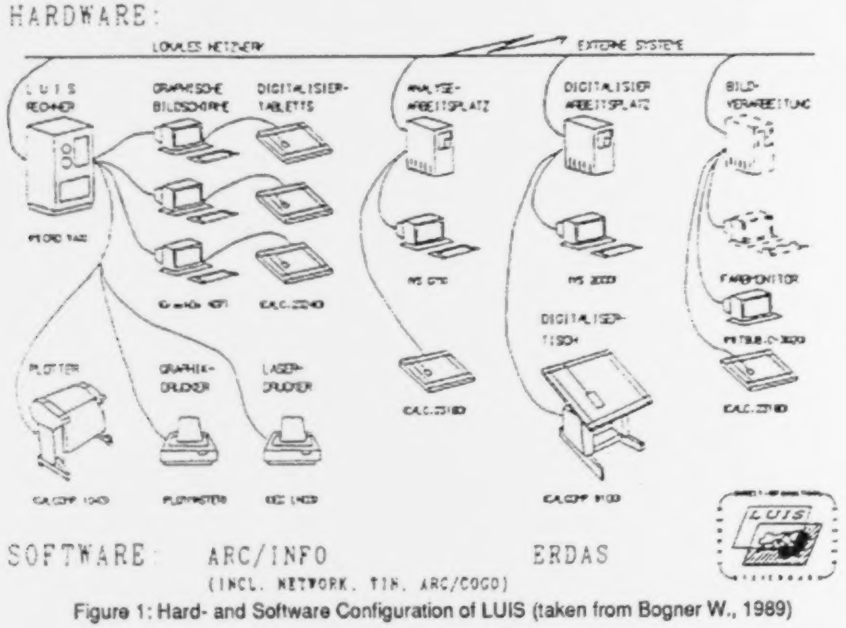

Figure 1: Hard- and Software Configuration of LUIS (taken from Bogner W., 1989)

have to be ensured by foresters. On the other hand, foresters are facing a variety of problems which require carefully planned actions.

Air pollution is endangering the state of the forests, as does excessive deer browsing, which, in some areas has reached such an extreme, that regeneration has been reduced to zero for the last 10 to 20 years. There are negative impacts from ski tourism or forest pasture and problems from the past, when exploitative harvesting practices resulted in large areas of even-aged stands, which are now feared to break down simultaneously, leaving large blanks. Without the protection by forest vegetation, erosion and avalanches may cause serious damage in the valleys below theses stands. To take action to improve the situation, sufficient access is considered a necessity by foresters. (Mayer H., 1984; Hintner W., 1986)

Environmentalists are concerned about the negative impacts of further access, ranging from damage during road construction itself, to long term impacts such as the division of ecosystems or the disturbances caused by excessive use of roads by tourists, hunters or farmers. They claim that because there are only so few previously untouched areas, that these areas should be left out of future activities and be preserved in their primeval state. (Hintner W., 1986)

In order to reach a mutually acceptable compromise, criteria have to be defined, which should help determine the policy to be applied to a certain region.

To define these criteria, an interdiciplinary working group was established, to negotiate the parameters to be used in this evaluation. Once these criteria were defined, the GIS was used to evaluate the landscape.

The result of this evaluation could be checked immediately and the effect of the given parameters could be demonstrated. It was possible to adapt and re-develop the model by constantly changing the input parameters until reasonable results were reached.

The aim of this project was an evaluation of the woody planted areas, covering all of Styria, in order to gain a decision base for further forestry planning. This decision base should prevent future conflicts by clearly outlining sensitive areas, according to criteria which are accepted by both foresters and environmentalists.

Realisation of the Project by Employing GIS Technology

At the beginning of the project, an inventory of required information was made. It contained the following information:

- Areas covered with forests,
- Areas of environmental value,
- Areas that cannot be accessed from existing roads,
- Areas where technical conditions for road construction are critical,
- Areas where road construction is likely to cause negative impacts on the landscape,
- Areas where the protection function of the forests is important,
- Areas where the state of forests is considered critical,
- Areas where the state of forests is considered normal.

Sources of Information

This information could be gained from the following sources

1. Topographic map at 1:50 000 scale:
   Forests.
   Existing roads
2. Maps of nature reserves, environmentally sensitive areas, water reserves at 1:50 000 scale:
   Zones of environmental value
3. Forest development plan at 1:50 000 scale:
   Evaluation of forest functions,
   Information on the state of forests,
   Basic information on geologic risks and dangers.
4. Geologic maps at 1:50 000, 1:75 000 and 1:200 000 scales:
   Information on critical conditions for road construction, slide zones, erosion areas,etc.,
5. Elevation model

Digitizing of Information Levels

The environmental information system was installed only a couple of years ago and therefore the amount of data already entered into the system and ready for analysis is rather sparse. Except for the elevation model, which was bought from Federal authorities, all the other levels of information had to be entered into the system before analysis could be started. This problem is probably familiar to all those who have been involved in establishing a geographic information system. In addition to the costs of hard- and software, the costs of adapting the existing information for automation and entering data into the GIS have to be calculated from the beginning, so that unpleasant surprises are prevented, which might endanger the acceptance of the new technology.

The five layers of information, which are listed above, were entered into the GIS, using the following procedures:

Figures 2 to 12 are at an approximate scale of 1:460 000.

1. Topographic Features

Forests: During the production of the 1:50 000 maps of Austria, the borders of forests are added as an additional layer. Therefore, it was possible to obtain this layer from the 'Bundesamt für Eich- und Vermessungswesen' (Federal Office for Survey) and to use a scanner for automation. Because this layer contained only binary information (no forest/forest) the conversion was not a very complicated process.

The digitizing of existing forest roads was a more sophisticated process, as there were different types of mapped roads which could serve as forest roads. For the first test runs of the project, simple manual digitization was chosen to transform these features into the GIS, but for further applications, scanning will be inevitable. In addition, manual actualisation of the forest road network is necessary, as

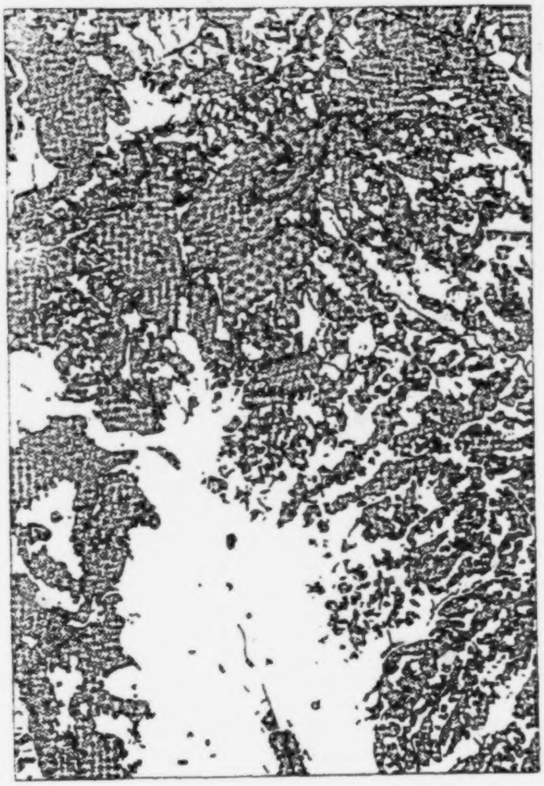

Figure 2 WAL

each year about 600 km (BMLUF, 1988) of forest roads are built in Styria, while the latest issues of the 1:50 000 map date from 1984. There have also been considerations about the use of SPOT satellite images for this purpose, but until the end of 1989 these data were not available within the Styrian administration and the forest department could not afford to acquire them for only this project. But now such images have been purchased by Styria and so the possibility of using SPOT 10 m x 10 m resolution imagery for the mapping of forest roads and other features will be examined.

2. Existing Reserves:

The borderlines of existing nature reserves or water reserves can be manually digitized without too much effort. These borders, however, are related to features of legal relevance; (i.e., cadastral borders) therefore, it is advisable to enter them using a direct coordinate input in order to use these data for other purposes. For large scale overviews, though, digitizing from 1:50 000 maps is considered a legitimate means of generalization. Each type of reserve is indicated by different shading, so areas which are part of both types of reserves can be seen.

Resulting Coverages: ZUL (nature reserves)
ZUW (water reserves)
reserves (union of ZUL and ZUW)
(Figure 4)

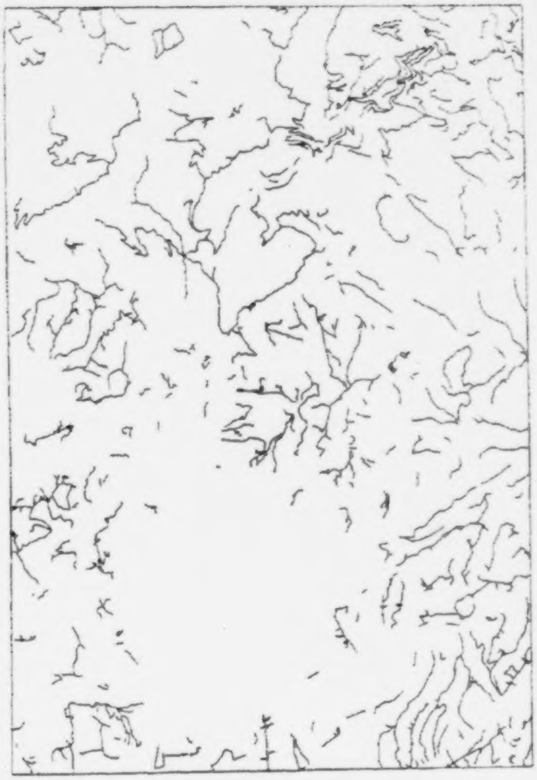

Figure 3 FOS

3. Forest Development Plan

This plan, established by the Austrian Forest Service, consists of a set of maps, descriptions and statistics. Basically, it contains an evaluation of four essential functions of woody planted areas; yield, protection, welfare and recreation. These functions are assigned values from 1 to 3, where 3 is the highest level of importance. If more than one function is assigned a 3 in one area, then the ranking is protection, welfare, recreation and yield. In addition, there is information on the state of the forests, possible dangers and suggested measures.

The maps in 1:50 000 scale were digitized manually. The function values were added as attributes into the PAT of the digitized coverages. The further descriptions of the areas, dangers, measures etc., were first established as dBASE-data using a PC and then linked to the ARC/INFO system. In Figure 5, areas where functions other than yield are considered most important are shaded. Resulting coverage: FDP (Figure 5)

4. Geologic Information

This layer of information represents the most sophisticated part of the input phase of the project. Geologic maps in 1:50 000 or smaller scales do not exist for all parts of Styria. Geologic mapping is done by federal authorities and the province has no funding for this purpose. Geologic maps

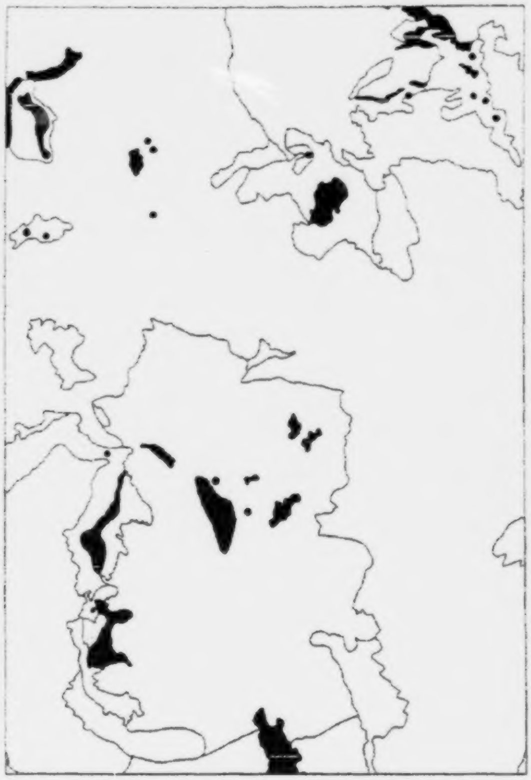

Figure 4 Union of ZUL and ZUW

contain such a variety of information that the automation process has to be well-planned and prepared. Some pilot projects however, have been launched in automating geologic maps but for the current project, the area covered by these tests is still too small for large scale evaluations.

Basic information on the geologic situation can also be taken from the forest development plan, as geologic conditions that represent possible dangers (like slide zones or erosion areas) are mentioned in the additional function zone descriptions in the plan.

5. Elevation Model

The computerized elevation model of Styria was used to calculate zones of different slopes. Three zones were defined, which represent different grades of probability that forest road construction might cause negative impacts to the landscape.

SLOPE 1: less than 60% no negative impacts expected
SLOPE 2: more than 60% less than 100% (SLODANG) negative impacts are possible
SLOPE 3: more than 100% (SLOCRIT) negative impacts are inevitable

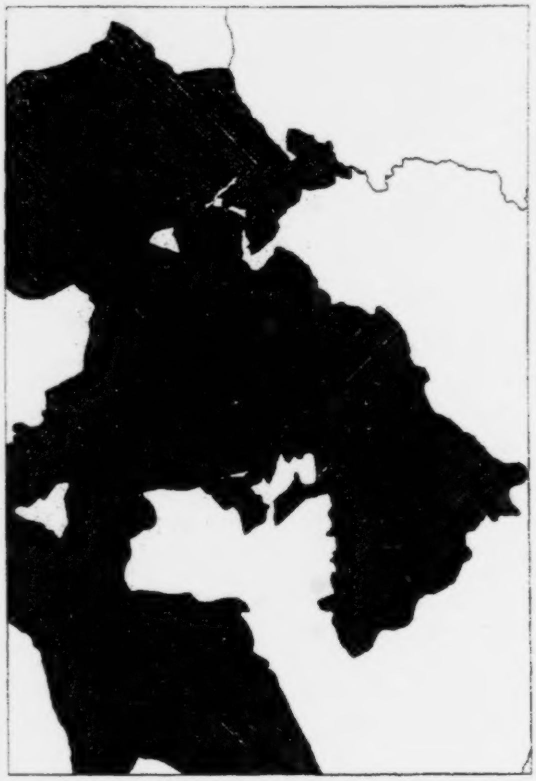

Figure 5 FDP

Definition of Zoning Criteria

As a result of the overlay process, different zones were defined, where different policies will be applied.

First, the two coverages FDP (forest development plan) and WAL (areas covered with woods) were overlain, so that the areas in the FDP were reduced to the the forest areas. This coverage was called FDWAL and served as basic input for further steps. In Figure 6, areas where the protection function is assigned a value of 3 are shaded black.

Five types of zones were defined, the characteristics of which are listed below. 'PROCEDURE' describes the ARC/INFO command sequences, which were applied to obtain the results. Please note that these are descriptions, not command listings. For further descriptions of the commands, please refer to the ARC/INFO manual (ESRI, 1989). The figures show the extent of each zone, reduced to forest-covered areas. The areas contained in the individual zones are shaded black.

1. Zones outside of environmentally sensitive areas, where no further restrictions (exceeding existing laws!) are to be taken.

This zone contains all areas outside of reserves.

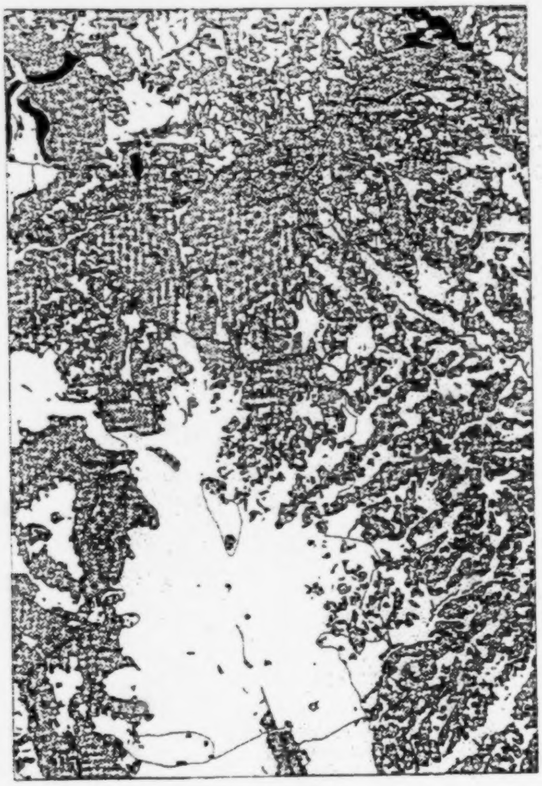

Figure 6: FDWAL

PROCEDURE: RE SELECT NO RESERVE AREAS from
RESERVE to get NORESERVE

2. Areas, within protected areas, where impacts of road construction are considered intolerable.

This zone contains areas within reserves which are critically sloped or under geologically critical conditions.

PROCEDURE: ERASE FDP with NORESERVES
to get AREAS WITHIN RESERVES
(AWR)
CLIP AWR with SLOCRIT to get
AWRSLOCRIT
RESELECT GEOLOGICALLY DANGEROUS ZONES from AWR to get AWRGD
UNION AWRSLOCRIT with AWRGD to
get ZONE 2

3. Zones within protected areas, where regular forestry is continued, including the construction of forest roads.

This zone contains areas within reserves, where yield is considered the most important function of the forest and the forests condition is not critical.

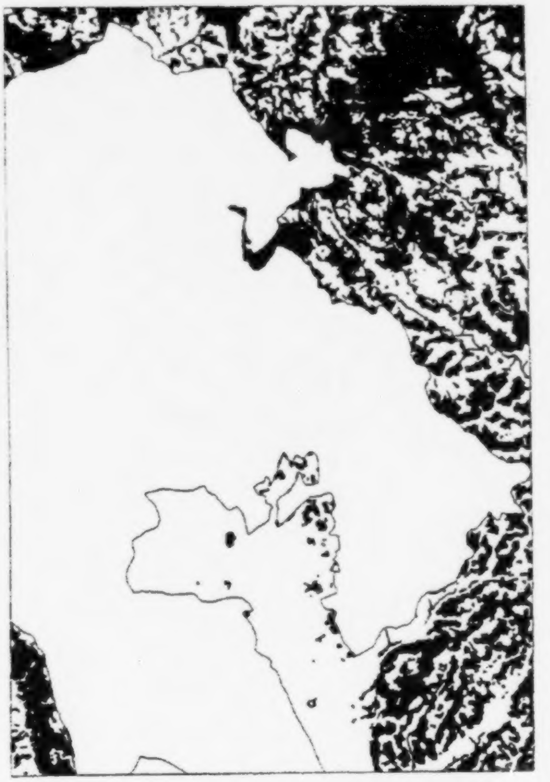

Figure 7: Zone 1, NORESERVE

PROCEDURE: RESELECT AREAS, where YIELD is
MOST IMPORTANT from AWR to get
AWRCRCN
RESELECT NON-CRITICAL CONDITIONS from AWRCRCN to get ZONE 3

4. Zones within sensitive areas, where human influence is absent, though road construction is technically possible, but negative impacts of road construction are considered too strong and forest conditions do not require further human intervention.

This zone contains areas within reserves, where the condition of forests does not require human intervention and where slope or geological conditions are dangerous, so that road construction is likely to cause too much damage to the landscape.

PROCEDURE: RESELECT AREAS, where PROTECTION VALUE ≥ 2 from AWR to get
AWRPV2
CLIP SLO2 with AWRP to get AWRSLO2
UNION AWRSLO2 WITH AWRPV2 to get
AWRSLOPV
RESELECT AREAS with SPECIAL ENVIRONMENTAL VALUE from RESERVES to get SEV
CLIP SEV WITH AWRSLOPV to get
ZONE 4

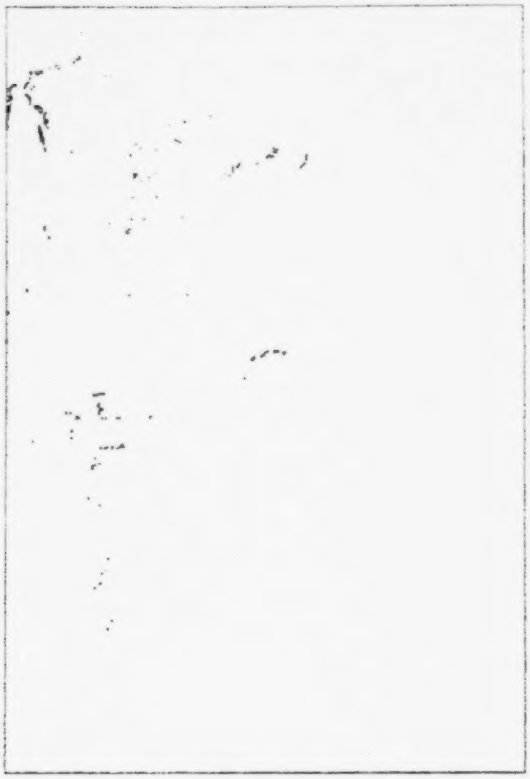

Figure 8: Zone 2

5. Zones within sensitive areas, where the protection function of forests has to be sustained.

This zone contains areas within reserves, where the state of forests requires human intervention and where welfare functions are considered of high value.

PROCEDURE: RESELECT AREAS of HIGH WELFARE-FUNCTION-VALUE from AWR to get AWRCRC

a) by building forest roads in order to take the necessary actions

This zone is within Zone 5, where neither geologic conditions nor slope is dangerous, so that damage to the landscape is within acceptable limits.

PROCEDURE: RESELECT GEOLOGICALLY NOT CRITICAL AREAS from AWRCRC to get AWRCRCGN
CLIP AWRCRC with SLO1 to get AWRCRCSLNO
UNION AWRCRCGN with SLO2 to get ZONE 5A

b) other methods have to be applied

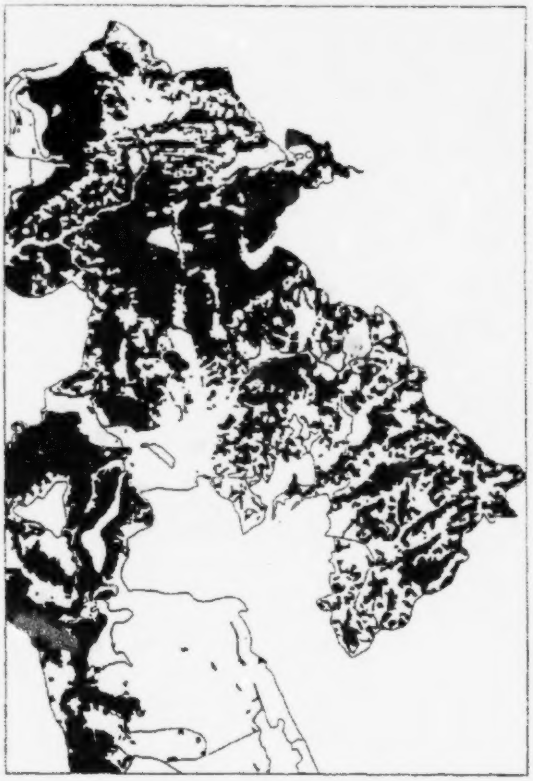

Figure 9: Zone 3

This zone is within Zone 5, where geologic situations or slope represent dangerous conditions, so that road construction may cause a negative impact to the landscape.

PROCEDURE: RESELECT GEOLOGICALLY DANGEROUS AREAS from AWRCRC to get AWRCRGD
CLIP AWRCRC with SLO 2 to get AWRCRCSLODANG
UNION AWRCRCGD with AWRCRCSLODANG to get ZONE 5b

Each of these zones can be displayed individually, but for overview purposes, a zonation map containing all zones, is produced. For the Zonation Map, which is displayed at a reduced scale (original scale 1:50 000), all the areas covered by the different zones have been shaded, whether they are covered by woods or not.

Current State of Access

In order to determine the necessity of new forest road projects, buffer zones were calculated around existing roads. Theses zones represent the possibility of access from existing roads and are contained in a coverage called BUFFOS. Areas which are not yet accessible from existing roads can thus be detected.

Figure 10 : Zone 4

PROCEDURE: ERASE WAL with BUFFOS to get NOACCESS

These areas represent the really critical zones, where necessity of access (from the view of a forester) stands against the value of untouched nature (from the view of a conservationist). And it is here where the zonation done by the GIS should help to avoid conflicts.

So, finally an overlay of unaccessed areas and the sensitivity zonation is performed and within each zone the according policy will be applied.

It is obvious that storage space and processing time could be reduced if all the zone-defining procedures were performed only within the NOACCESS areas. On the other hand, evaluating the whole area gives a good opportunity to check the reliability of the chosen method, by comparing the real impacts of finished projects to the expectations in the zonation.

Scale Limitations
Because of the rather large scale of input data, the above zonation, in some cases, has to be supported by field surveys in especially critical zones. It does, however, help to avoid conflicts by defining extremes.

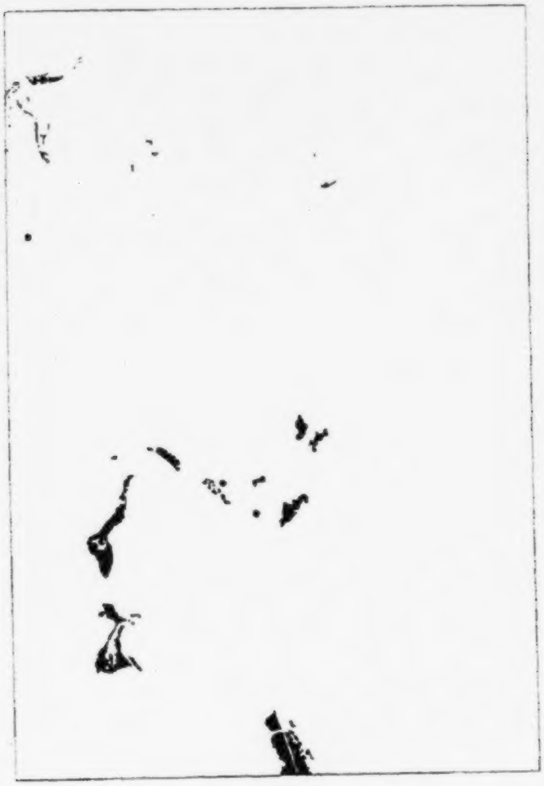

Figure 11: Zone 5a

Especially in Zone 5, input data may not be sufficient to accurately define the borders between Zones 5a and 5b. In areas like these, field surveys will have to be made. (Huetter R., Kalhs J., 1989)

The use of more accurate input data, like aerial photographs could improve the accuracy of results.

Advantages of GIS
Employing GIS technology for the zonation of sensitive areas has proven successful.

Possibility of Further Analysis
In addition to the primary result, a zonation of sensitivity classes, the information which was entered into the GIS is now available for further analyses. This is probably one of the main advantages that the use of the GIS has offered. The overlay of different information might have been possible without this technology, but the invested effort would have been of no further use, as the result would have been just another set of maps.

The automation of the forest development plan (FDP) is one example of further opportunities, as this plan contains a lot of information, which, for the first time can be graphically displayed. As a useful side effect, the automation of the

Figure 12: Zone 5b

FDP maps offered an opportunity to check and correct the matching of neighbouring maps in this plan; during this process, existing errors were detected and removed.

The problem of adapting data of different accuracy levels for input into the GIS and the varying methods of automation, ranging from scanning to direct keyboard coordinate input, offered useful experiences for the Styrian Forest Service and will prove helpful for further applications.

Further Opportunities for 3D Display

Within the field of forest road construction, there is another useful feature of the GIS which supports decisions on future projects. By displaying a 3D elevation model, it is possible to show the impacts of a road project on a certain landscape. This is especially helpful in public presentations.

For the planners and executives involved, such 3D displays do not offer much additional information and the processing of the required files is still takes a long time, so this feature cannot be used on a regular basis.

In the face of a concerned public, which tends to distrust the so-called 'experts', the use of modern presentation techniques, which include 3D display may help to support arguments more than volumes of figures and statistics.

Limitations

The current limitations for to use of GIS technology by the forest service of Styria have been outlined during this project.

- The lengthy processing time and large storage space reduces the frequency of more sophisticated applications to only a few experimental projects.

Suggested improvement:
Future hardware developments may make this comment obsolete, until then careful planning and organization should avoid data redundancy and unnecessary processing steps.

- The man-hours for further coverage automation would require additional personnel, which is affordable only on a limited basis.

Suggested Improvement:
Collaboration with other departments and authorities could result in the exchange of different information layers. Effective presentation of achieved results could convince the public and politicians of the importance of GIS technology and result in more generous funding.

- For some applications, the accuracy of existing data will not be satisfactory (e.g., geologic data for risk analysis, information on the state of forests).

Suggested improvement:
For the automation of new information layers, only the highest accuracy level possible will be applied. Aerial photographs can be used to gain a multitude of information with satisfying accuracy.

Future Aspects

The capacity to perform quick analyses on an ever increasing amount of environmental data within relatively short times makes the use of a GIS a necessity for all those who are involved in environmentally relevant decisions.

Nevertheless, the quantification of quality features requires a compromise on parameter values which has to be reached involving all interest groups; it cannot be performed automatically. GIS technology can support decision processes but it cannot replace human responsibility for decisions.

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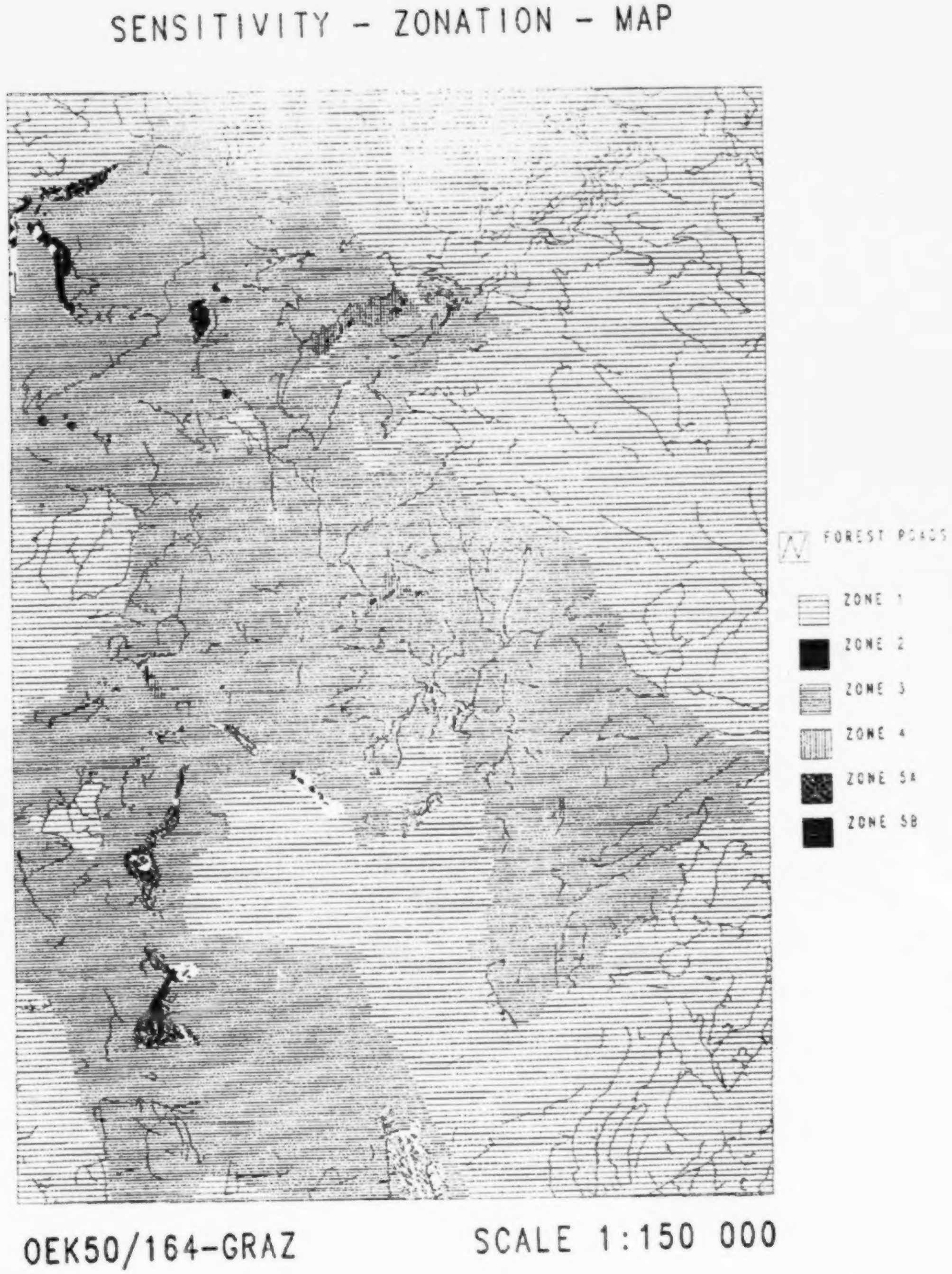
SENSITIVITY - ZONATION - MAP
FOREST ROADS
ZONE 1
ZONE 2
ZONE 3
ZONE 4
ZONE 5A
ZONE 5B
OEK50/164-GRAZ
SCALE 1:150 000

Figure 13: Sensitivity Zonation Map

Bogner. W., Rossin R. et al., (1989). **Landes Umwelt-Informationssystem, Umweltschutzbericht 1988 des Landes Steiermark S.34 ff.**, Amt der Steiermärkischen Landesregierung, Graz, 1989

Huetter R., Kalhs J., (1989). **Waldschadenskartierung und Ermittlung sensibler Zonen im Forststraßenbau,** Tagungsbericht Umweltwissenschaftliche Fachtage 1989, Forschungsgesellschaft Joanneum, Graz, 1989

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Monitoring the Impact of Off-road Vehicles

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Abstract

Off-road vehicle (ORV)use has created a visually prominent landscape pattern in many areas of the southwestern United States. A system of parks has been established in California specifically dedicated to use by ORVs. A goal of ORV user groups and park managers alike is the development of a monitoring system to aid in the preservation and rehabilitation of environmental quality to sustain future use. Using aerial photography, changes in land use, vegetation types, and trail expansion were mapped for Hungry Valley State Vehicular Recreation Area and then analyzed using a GIS to quantify the rate and character of change associated with this recreational use.

Background

Geographic information systems technology has improved the range of options open to resource managers for monitoring and rehabilitating the environment. The term 'environmental quality' can be considered a culturally and regionally dependent theoretical concept based on human habitat goals and minimum competencies of ecosystem viability. The individual components of environmental quality, portrayed by a series of measurable variables, are expressed in a spatial context; hence, the need and potential utility of a geographic information system. The monitoring of processes such as erosion or vegetation alteration requires much attention to spatial detail. Did, for example, the erosion occur on a flat valley bottom or as a gully along a hillside of steep slope? Does vegetation lost on a north-facing slope generate a similar problem if it were removed from a south facing slope? There are a myriad of specifically spatial context relationships which form the core information essential in the daily operations of an effective resource management program.

There continues to be considerable controversy over the use of open space, particularly public lands, by OHV enthusiasts. At the heart of this controversy lies the issue of environmental quality and the charge that this recreational activity causes negative impacts to the environment, which infringe on the general public's right to 'quality' recreational environments. There is mounting scientific evidence indicating that OHV use causes and accelerates the processes of erosion, vegetative cover loss, and wildlife habitat destruction. Areas such as Hungry Valley which have been used for OHV recreation, develop a characteristic landscape pattern with barren, spidery thin trails crisscrossing over slopes and flatlands. The extent and positioning of these trails are linked both to processes of erosion and vegetative cover loss and the individual proclivity of the rider. It is important to note that a goal of OHV enthusiasts, park managers, and resource specialists alike is the development of a spatially competent environmental monitoring system to aid in the preservation and rehabilitation of environmental quality within the park to sustain future use.

In fall 1988, SDSU Geography Department's Center for Earth Systems Analysis Research joined with the State of California, Department of Parks and Recreation, Off-Highway Motor Vehicle Division to conduct a pilot study of the utility of a GIS in Hungry Valley State Vehicular Recreation Area (SVRA). Hungry Valley is a park encompassing over 18 000 acres which has been operated since 1980 as an off-highway vehicle (OHV) recreation spot. It is currently the largest SVRA in the state park system and is located about 30 miles north of Los Angeles. Thus, it potentially meets a significant regional recreational need. Situated in California's Transverse Ranges, the park is unique in its topographic, geologic, and biotic diversity. It is this same diversity of physical environment which also makes it attractive as a recreational area.

Goals of the Study

The construction of a GIS database to spatially address this physical environment was approached with two fundamental goals in mind: 1) to collect and automate existing data in a spatial format; and 2) to outline an efficient methodology for future resource monitoring and environmental assessment. The choice between a raster- and vector-format GIS was made based on considerations of compatibility with existing information as well as the nature of the variables to be emphasized in the monitoring process. Most of the information about the park was in the form of existing thematic maps containing point, line, and polygon features. Also, since trails and trail extent were important variables, a vector-based GIS was determined to be the optimal format for the majority of core information. Arc/Info, a vector-based software system, was used in the implementation of the GIS. This choice of format should not be seen as a significant limitation for data analysis since the capability to work with both raster- and vector-formatted data together is now available. Thus, new data derived from raster-based sources can augment existing information in vector format.

Constructing the Data Base

A preliminary data base of twenty variables was constructed from existing map sources. As is the case in many collaborative or applied projects, several issues regarding the quality of existing information had to be addressed. For example, with respect to Hungry Valley, the thematic range of data available is good; however, individual maps were generalized at different scales and were prepared with varied levels of accuracy. Realizing that the quality of a GIS is only as good as its weakest link (and error or distortion will multiply rather than diminish), scrupulous documentation has been maintained for each data layer or coverage, indicating the scale of data collection as well as the scale used during the automation process (i.e., digitizing). In this way, an estimate can be made of the level of generalization of the end product.

One of the important insights gained during this preliminary phase was the realization that different layers of information reflected environmental conditions coincident with the date of data collection. Thus, each layer of information portrayed a specific topic at a specific time. Within an environment such as Hungry Valley, which is subject to rapid physical change over short periods of time, the use of a geographic information system facilitates temporal comparisons. Equally important, it becomes obvious that change is a relative concept depending upon the individual variables considered as comparators. Hungry Valley SVRA had been used informally for OHV recreation since the early 1970s, prior to acquisition by the Department of Parks and Recreation. Thus, the environmental conditions extant in the park at the date of purchase may be somewhat biased for use as a baseline for maintaining an 'environmental quality' based on the park's once pristine, natural state.

Methodology for Resource Monitoring

Two goals were determined in the development of a methodology for resource monitoring in Hungry Valley: 1) the establishment of a comparison datum and 2) the development of an efficient method for integrating current information on resource conditions. Two key variables were determined to be of utmost significance in the data collection: the vegetation mosaic and the patterns of trails associated with the park's use. The determination of an adequate comparison datum was constrained by the need for accurate spatial data covering the entire park. Historic aerial photography dating from 1940 and 1954 were located at a scale of 1:20 000 covering the entire park. Additional sets of aerial photography for 1978, 1984, and 1988 were also acquired. From 1978 onward, it was possible to acquire photography more closely matching the scale of the general data base (1:12 000).

The photography was interpreted using a mirror stereoscope and the information regarding boundaries of vegetation types and trails was transferred to topographic basemaps using terrain matching. This technique is low-cost, time efficient, and requires minimal technological support. These new map coverages were then automated and compared through time to assess the extent of change in the vegetation mosaic and trail network over the past 50 years.

Results show that valley areas now most heavily affected by trail expansion are the same areas which were subjected to agricultural use. Thus, the processes of erosion have been in action for a longer period of time than was originally suspected and have been aggravated or accelerated, rather than initiated by OHV use. Other information derived from the historical analysis of spatial change in vegetation patterns has indicated the invasion of large perennial shrub species into areas previously cleared for human use.

With further refinement, the data base will be a valuable aid in trying to plan for restoration of barren and heavily impacted areas, not only in terms of accurate estimates of total acreage and physical composition, but also in the indication of the history of vegetation in specific locations. Resource managers presently can estimate the range of vegetation types, but lack concrete data on the specific spatial extent or length of time of vegetation loss. These variables are critical in the planning for successful restoration programs.

Conclusions

This pilot study has been successful in integrating historical data into a geographic information system and in formulating an efficient method for resource monitoring. In a very practical sense, the existence of a temporal data base for the park is invaluable to resource managers who assess change and plan the desired character of future OHV environments.

Acknowledgements

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Using a Geographic Information System for Prescribed Fire Management at Cuyamaca Rancho State Park, California

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Abstract

Fire is an integral part of wildland ecosystems in southern California (Mutch 1970, Haines 1971). The California Department of Parks and Recreation (CDPR) recognizes that decades of fire suppression has created ecological imbalances within the wildlands that it manages. CDPR has sought to reestablish fire as an ecological force in its wildland parks. The planned application of prescribed fire is recognized as a practical tool to achieve this goal. Cuyamaca Rancho State Park is a 10 000+ hectare (25 000 acres) State Park unit in the Peninsular Mountain Ranges of eastern San Diego County. The Park is characterized by a complex mix of woodland, coniferous forest, chaparral, and grassland vegetation. In 1983, a Prescribed Fire Management Program was established in the Park with the goal of reintroducing fire into the Park's wildland ecosystems. Since 1987, an ERDAS Geographic Information System (GIS) has been used to help prioritize areas for burning and to generate the necessary project burn plans. The GIS has also been used to generate fire intensity maps of the Park which predict fire behavior under wildfire and prescribed burn conditions.

The Fire Management Problem in Southern California

Southern California's celebrated Mediterranean climate has contributed to the occurrence of frequent wildfires in this region (McCutchan 1977). The climate is typified by an extended period of warm season drought when evapotranspiration far exceeds precipitation (Axelrod 1977). The moisture content of living plant material can drop to very low levels during the dry summer and cause these fuels to become highly flammable. Additionally, the warm dry climate retards the decomposition of dead natural fuels and leads to their accumulation (Dodge 1977). The accumulation of dead fuels and the high flammability of live fuels during extended periods of drought encourage the frequent incidence of fire.

The passage of the Forest Protection Act by the California State Legislature in 1905 and the takeover of the national forest system by the Bureau of Forestry in the same year (Pyne 1982) initiated the era of modern wildland fire suppression in southern California. Since that time, with steadily increasing efficiency, wildland fire has been systematically prevented and suppressed. As a result, wildland fuel loads have increased dramatically (Dodge 1972). Ironically, because of the heavier fuel loads the fires that do burn tend to be larger, burn at a greater intensity, and are much more expensive to suppress (Minnich 1983).

There has also been a high ecological cost to systematic fire suppression in California. Frequent low intensity fires have been found to play important roles in nutrient cycling (Harris and Covington 1982). Fire can increase diversity in aged chaparral (Patric and Hanes 1964; Westman 1984) and can have a suppressive effect on invasive non-native annual grasses (Parsons 1989). Fire can retard the invasion of brush into native grasslands and into the understory of conifer forests (Cooper 1961). Fire plays an important role in the reproduction of many plant species; the seeds of some species of non-sprouting chaparral will not germinate unless first scarified by fire (Hanes 1977). Fire is also required to open the serotinous cones of some conifers (Vogl et al 1977) and is necessary to prepare the seed bed of others (Sacket 1984). The net ecological effect of fire exclusion in Cuyamaca Rancho State Park has been to allow expansion of chaparral into other vegetation types, reduce biotic diversity in brush and forested lands, and allow exotic annual grasses to dominate the park's grasslands (Gaidula 1983).

The Prescribed Fire Management Program

Realizing the importance of fire's role in native wildlands, the California Department of Parks and Recreation (CDPR) has sought to reintroduce fire to the ecology of Cuyamaca Rancho State Park. In 1977 the first of a series of experimental prescribed fires was conducted under the direction of Dr. Harold Biswell, Professor Emeritus, University of California, Berkley, a pioneer in the modern application of prescribed fire. In 1982 CDPR prepared the Prescribed Fire Management Program (PFMP) for Cuyamaca Rancho State Park and an accompanying Environmental Impact Report (EIR). The purpose of these documents was to systematically plan the application of prescribed fire so that the long-range management goal of reestablishing fire's natural role within the state park could be accomplished. The PFMP and EIR contain detailed information on the climate and weather, topography, geology, soils, vegetation, fauna, and modern cultural features of the park as well as sensitive resources such as rare plants, sensitive wildlife habitats and sites of archaeological or historic importance which might be adversely affected by fire. In order to effectively access this information the use of a GIS was proposed. The San Diego State University (SDSU) Department of Geography was contracted to provide this service.

Fire Prescriptions and Fire Behavior Modeling

An important key in using fire to accomplish resource management objectives is to accurately anticipate the fire behavior which will result from an ignition. Fires which burn at a high intensity are difficult to control and can cause damage to the resource values they were intended to enhance. Fires whose intensity is low may not accomplish the desired resource management objectives and may require a larger investment of labor to ignite and maintain than is economically feasible (Brown and Davis 1973).

In order to to burn safely and effectively, fire managers have developed predetermined sets of environmental conditions, called prescriptions, which will yield fire behavior within predictable parameters when applied to a specific type of wildland fuel. A prescription usually includes those variables of fuel moisture and weather which can be readily observed or determined at a burn site. Originally, prescriptions were based on the individual experience of prescribed fire managers and fire fighters. However, over time more objective techniques have been developed. Fire behavior modeling, the use of mathematical models to predict fire behavior, is such a technique.

Fire behavior models were developed to help fire fighters anticipate wildfire behavior. Rothermel (1972) developed the original mathematical equations currently used for predicting fire behavior. The equations have been used to generate fire behavior models which are keyed to specific wildland fuel types. These models have been applied in several different formats including nomographs (Albini 1976), field guides (NWCG 1981a), programmable calculators (Burgan 1979) and computers (Andrews 1986). The value of these predictive models is that they establish an empirical basis for fire behavior predictions.

To make a fire behavior prediction the appropriate fuel model for the type of vegetation or fuels in question is selected. Then inputs are entered for the variable conditions of fuel moisture, topography and weather that exist in that particular area at the time of ignition. These inputs include some or all of the following: live fuel moisture, dead fuel moisture, elevation, slope, exposure, wind speed, relative humidity, cloud cover and temperature. The model then produces a prediction of fire behavior in fire intensity (heat release per unit area, flame height) and rate of spread. Prescribed fire managers use these models to predict the intensity of fire behavior that may result during a prescribed burn.

A weakness in applying these models to prescribed fire is that a single prediction of fire behavior may be applied over a relatively large spatial area. Some or all of the conditions which are entered as input values will not be constant over an entire burn plot. Also, two or more vegetation types may be present and intermixed within a single area. Thus a single prediction, based on one fuel model and a single set of input values, will not accurately represent what is in reality a range of values. Albini (1976) considered the lack of sensitivity to variability the dominating source of error limiting the validity of fire behavior predictions.

Combining Fire Behavior Models and GIS

In order to increase the sensitivity of fire behavior models to variability within Cuyamaca Rancho State Park, fire behavior models were combined with the ERDAS GIS which had been prepared from the PFMP. The fuel models used are those which correspond to the vegetation types mapped in the PFMP and which have been digitized into the GIS. The input values entered into the models are taken, when possible, from other layers in the GIS. The final products are maps of the park displaying predicted fire intensity. There are two advantages to taking this approach over traditional fire behavior modeling; the prediction produced by the GIS is sensitive to the variability in the GIS data base, and the final output is displayed spatially so that fire behavior predictions can be linked to particular locations.

Fuel Models

The inventory of the Park's natural resources shows a division of the vegetation into chaparral, grass, and woodlands (Gaidula 1983). The woodlands in the Park consist of three communities: conifers, oaks and a combination of the two. According to the description of the 13 fuel models developed for the National Fire-Danger Rating System, fuel model number 10, timber litter and understory, may be used for any forest type if heavy downed materials are present. A survey of the woodlands in the Park revealed an abundance of dead woody fuels. Based on the descriptions of the fuel models from the National Fire-Danger Rating System (NWCG 1981), the following three fuel models were selected for this project: short grass, chaparral, and timber litter and understory. These fuel models were used as inputs to the fire intensity models.

Energy Release

Models which predict fire intensity were adapted for use with the GIS for mapping spatial predictions of fire intensity. Two existing fire models were selected, a model developed by the Boise Interagency Fire Center (BIFC) (NWCG 1981a,b) and Rothermel's (1972) rate of spread and fire intensity model. The BIFC model was considered because it allowed more input from the GIS while Rothermel's model was suggested by the CDPR.

Fire models, like wildfires themselves, are dynamic in nature. They have been developed for on-site predictions which reflect current environmental, meteorological, and fuel conditions. Some of these parameters are held constant to generate maps of fire intensity using the GIS. A survey of the 13 wildfires that have occurred in this area within the last 65 years revealed that nine have been in the late summer or fall. The conditions reflected by the fire report of the August, 1986 Peak fire (Wands 1986) were used as values for wind speed, temperature, relative humidity, and time of year.

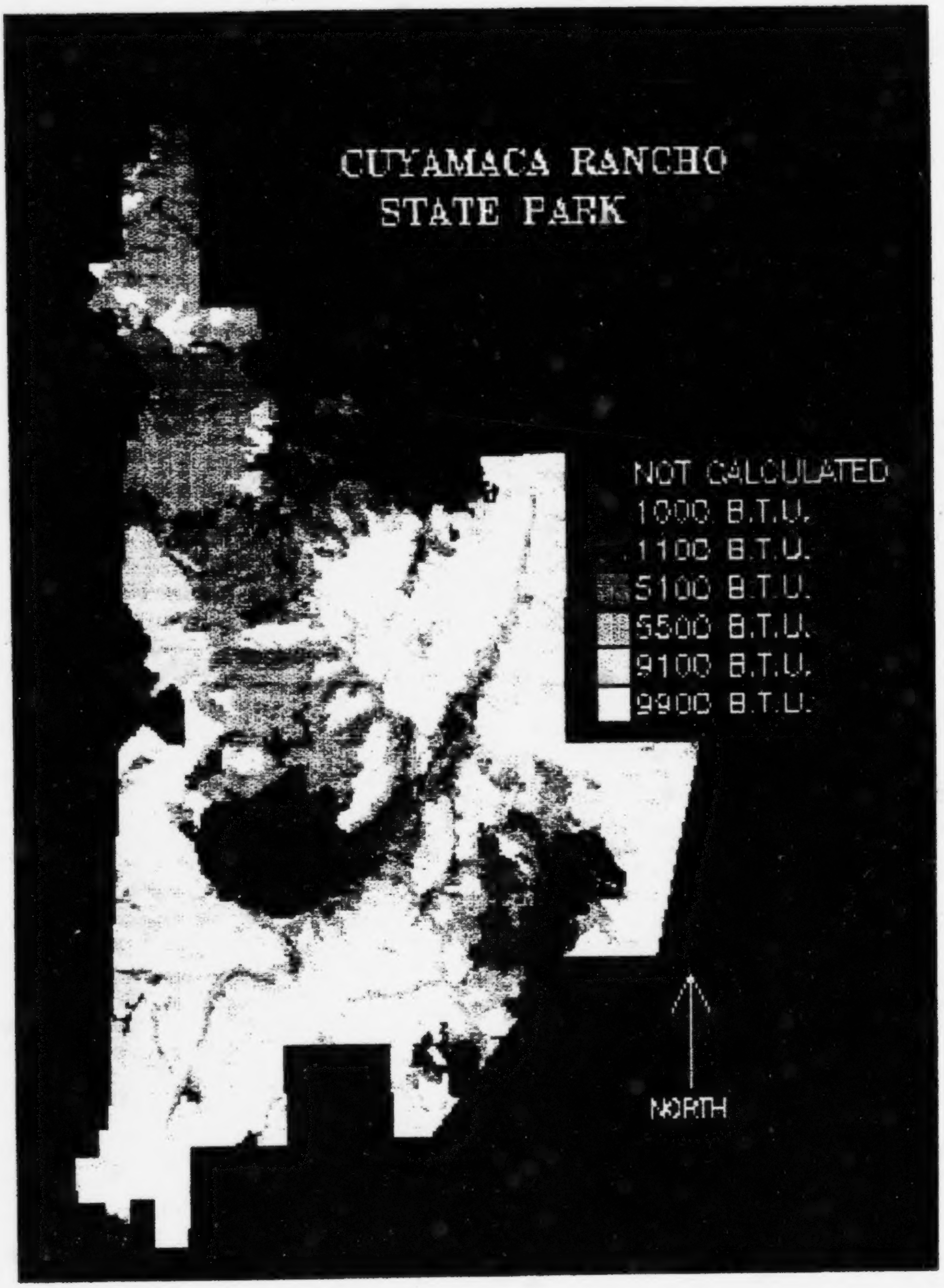
BIFC Fire Intensity Model

The BIFC model is based on a series of calculations. Input for these calculations comes from tabular data for a wide range of environmental conditions. The model used data from the GIS data base and lookup tables (NWCG 1981a) to create maps of fuel moisture, slope factor, wind factor, fuel models and fire intensity. The first step was to generate maps of fuel moisture. Values for dead fuel moisture were extracted from the tables, using temperature and relative humidity. Temperature and humidity were based on conditions which existed during the August 1986 wildfire (Wands 1986). These values were used in the creation of a map showing the beginning base for dead fuel moisture. Using the dead fuel moisture lookup table (NWCG 1981a) a correction factor for exposure was applied to the dead fuel moisture map. This was done by recoding the aspect map, then adding it to the map of dead fuel moisture. Data for live fuel moisture was extracted from the live fuel moisture content table (NWCG 1981a). The percent of moisture content was based on stages of vegetation development, and mapped by using fire history as a surrogate for age. The plant communities were then recoded into the three fuel models. (See the section on fuel models for an explanation of how these models were selected).

A map of wind factors was created by multiplying the wind speed from the Peak fire report (Wands 1986) by adjustment factors which were determined by the fuel type (NWCG 1981a). A slope factor was calculated using the correction factors for slope lookup table (NWCG 1981a). These values were used to create a slope factor map. The slope factor map was then added to the wind factor map to create a total correction factor map. This map was then multiplied by values extracted from a table which used dead fuel moisture and live fuel moisture to determine an intensity value. The intensity values extracted from the table represent values for no wind and flat slopes. By multiplying this value by the total correction factor map the influence of wind speed and slope is incorporated. The results were then used to create a map of potential fire intensity.

Rothermel's Fire Intensity Model

The second model used was Rothermel's (1972), a mathematical model based on a series of equations. The input parameters can be broken down into three groups: 1) fuel particle properties, 2) fuel array arrangement, and 3) environmentally related factors. The fuel particle properties consisting of particle density, heat and mineral content must be determined from lab analysis. In his article, Rothermel (1972) listed values for each of the National Fire-Danger Rating System's (NFDRS) fuel models. These values could be used in field applications. The listed values were used since laboratory analysis of fuel properties was beyond the scope of this study.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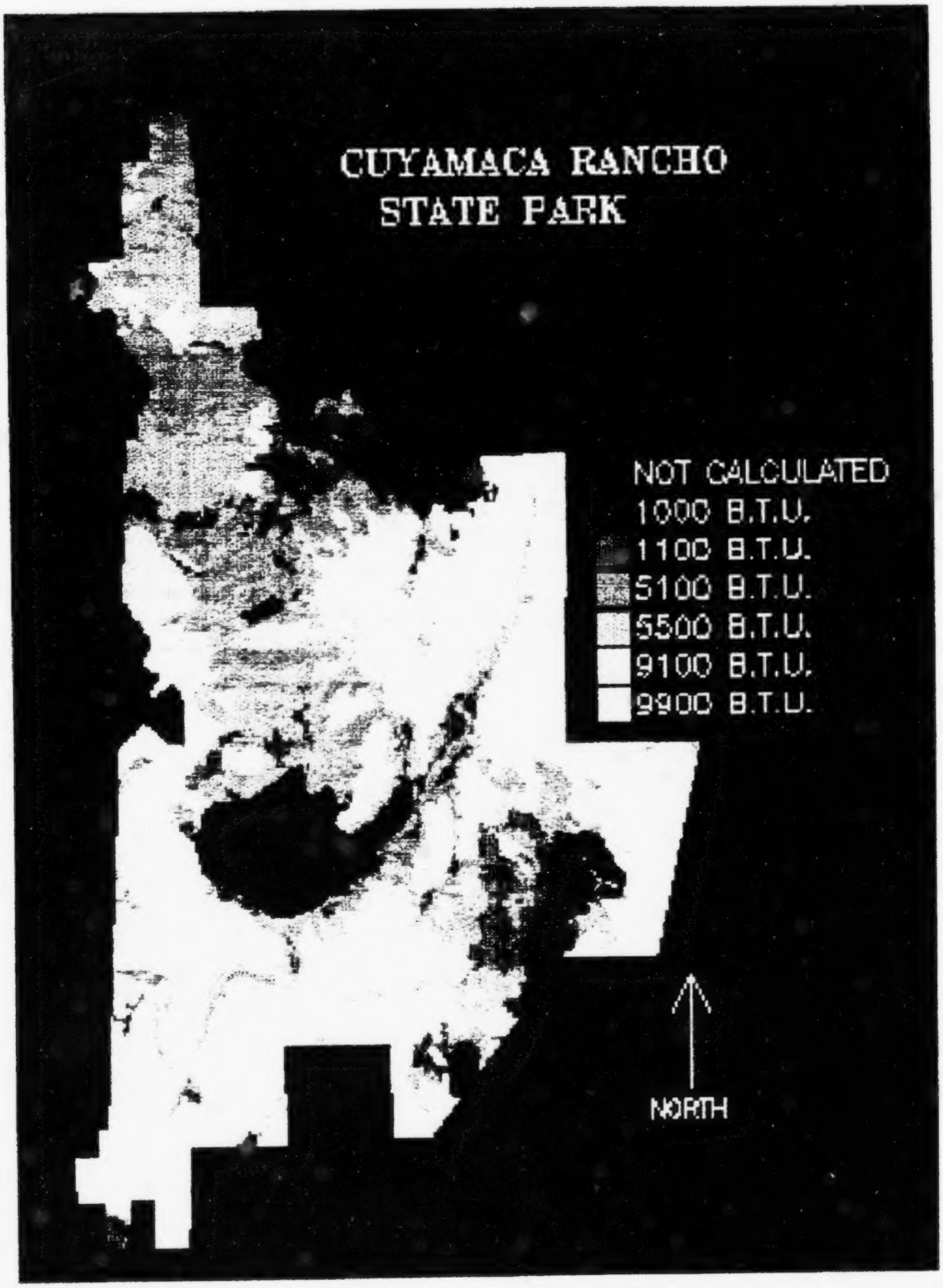
9900 B.T.U.
NORTH

Figure 1. Map of fire intensity using
Rothermel's fire intensity model.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NORTH

Figure 1. Map of fire intensity using Rothermel's fire intensity model.

For the fuel array arrangements, the fuel depth given by Rothermel (1972) for the NFDRS fuel models were used. Since the modeling was done for worst case scenarios, the loading by fine size class values were used (Rothermel 1972).

The GIS supplied most of the environmental inputs, e.g., exposure and vegetation, except for the highly dynamic variables of wind speed, temperature and humidity, which were held as constants. The aspect map was recoded to reflect dead fuel moisture. The vegetation map was recoded into fuel types. They were assigned values representing the calculated values of fire intensity from Rothermel's equations, minus the input for dead fuel moisture.

The last step was to multiply the map of dead fuel moisture by the map of fire intensity. This completed the calculation of the equation for intensity. Finally, these values were used to generate the map of potential fire intensity, Figure 1. The maps produced by the two fire intensity models displayed very similar patterns. Most of the difference can be accounted for by differences in the input parameters. The BIFC model showed more variation since more variables were used as inputs. Strong similarities did exist in the intensity predictions for each vegetation community. The reason for the similarities are the emphases placed on fuel types by the intensity models.

Analysis

The results of each intensity model were compared by spot field checks. Ten locations were selected from the test plot which had a variety of predicted intensities. Using the field applications guide for the BIFC model, estimations of fire intensity were calculated. Intensity predictions made in the field strongly correlated with those of the BIFC model. One area of conflict, location number eight, had a predicted value of 4,250 b.t.u. and a field estimate of 98 b.t.u. The predicted intensity value was based on chaparral as an input, but in reality pine and oak woodlands existed at the location. The area in question was an inlier of chaparral in the woodland community. Field investigation showed that the source data was not accurate. This stand of chaparral was several hundred meters north of its mapped location on the CSPR's vegetation map.

Fire intensity maps were then generated for prescribed burn conditions. These maps, along with the maps of wild fire conditions, were compared with the narrative fire reports from prescribed burns and the Peak fire (Wands, 1986). Using Albini's nomographs (Albini, 1976), and the Behave computer model (Andrews 1986), fire intensities were determined from observed fire behavior. In both cases, the models over-predicted fire intensity.

Conclusion

The fire intensity maps generated by this project have been useful in planning prescribed burns. The maps indicate to the fire manager the range of fire behavior that may be expected during a prescribed burn. This has been especially useful in locating potential control problems; areas where high fire intensity will occur adjacent to plot boundaries. It has also been helpful in planning ignition patterns, and in protecting sensitive resources which may be adversely affected by high fire intensities. The fire intensity maps and the GIS have not eliminated the need for thorough field work prior to conducting a prescribed fire; they have helped, however, to focus planning efforts and use field time more effectively.

Some problems have been encountered which, at present, limit the accuracy and utility of the GIS fire behavior models. It is the authors' opinion that the factor which has most limited the accuracy of the fire intensity maps is the process of generalization which takes place when vegetation types are classed into fuel models. Twenty-three different vegetative communities recorded in the PFMP were lumped into three generalized fuel models. Experience in conducting prescribed fires has shown that the flammability of some of the vegetation types that have been lumped together is often quite different. These differences are not reflected in the modeling process.

Fuel loading is another important factor influencing fire behavior that is not considered in the current fire behavior models. Downed fuel inventories conducted in the Park have shown that fuel loads in timber stands often vary by several orders of magnitude. Such differences will radically affect fire behavior. However, the models currently in use are not sensitive to these differences.

Some improvements intended to increase the accuracy and ease of use of the GIS fire behavior models will be pursued in the future. The developement of custom fuel models for Cuyamaca Rancho State Park that accurately reflect different vegetation types and fuel loads is the highest priority. Testing and validation of these models will be performed as prescribed fires are conducted. Another improvement which would increase the utility of the GIS models is to make the models user-interactive. The goal is to replace the static fire behavior maps with a program that could be adjusted in real time to reflect changes in fuel moisture and weather conditions. The attainment of these goals would give us an even more useful tool for planning fire management projects.

Acknowledgments

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Managing Resource Conflict

Session A6
GIS for Wildlife and Habitat Management - 2

An Information Systems Approach to the Preservation of Biological Diversity

Human Encroachment on Bear Habitat

Using GIS for Habitat Management in the Wake of Hurricane Hugo
Habitat Suitability Analysis and Impact Assessment with GIS-based Logistic Multiple Regression Modeling

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An Information Systems Approach to the Preservation of Biological Diversity

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Abstract
Biological diversity emerged in the 1980's as a major scientific and political issue. Scientific assessment efforts have been hampered by a lack of cohesive data sets and information on key factors in biodiversity. We describe, in concept, a framework for a comprehensive national diversity information system. This system uses GIS techniques to organize existing data and improve spatial aspects of the assessment. One potential type of GIS analysis, which could be conducted using such a system is the identification of gaps in the network of nature reserves for California, is discussed in greater detail. By employing an information systems approach, we firmly believe that available data can be used more effectively, and better management strategies can be formulated for the long term preservation of biological diversity at scales from local to global.

1. Introduction

Alarm over the accelerating rate of extinctions of plant and animal species and destruction of ecosystems has prompted a call to the scientific community to make comprehensive assessments of the status and trends of biological diversity (biodiversity) and recommend conservation strategies (Wilson, ed. 1988, U.S. Congress Office of Technology Assessment, 1987).

Herein, we present our concept for the development of a comprehensive biological diversity information system relevant to the sustained preservation of biological diversity. Outlined is a geographic information system (GIS) approach in which existing information can be input, managed, and analyzed, while needs for additional information can be identified. The system envisioned is multileveled and encourages the flow of data and information from local up to international levels and vice versa. Our intent in presenting this material now, prior to the establishment of the United States National Center for Biological Diversity, is twofold. First, we wish to notify the GIS community of the need for their skills in addressing this international problem of declining biodiversity. Second, we want to stimulate discussion on the potential for GIS for handling biodiversity data, so that implementation can be expedited. It should be emphasized that the design for a national biodiversity information system presented here is not meant to be the definitive solution; it is, we hope, only one of a number of valid approaches to a problem of significant local, national, and global concern. While the tropics are acknowledged to contain far greater diversity (and greater risk of mass extinctions) than temperate regions, all nations need to manage their development within ecologically sustainable limits (Lovejoy 1988). It is our belief that a GIS-based biodiversity assessment can be one key component in an overall strategy of ecological management and economical development.

Diversity is a complex concept, and the term is used in many ways. Most generally, diversity refers to the total number of species inhabiting an area. We use the term 'species richness' to convey this meaning. Individual ecosystems, defined by combinations of biological and abiotic factors, have both structural and functional diversity. The terms 'biological diversity' or 'biodiversity' will be used when we mean "...the variety and variability among living organisms, and the ecological complexes in which they occur." (U.S. Congress Office of Technology Assessment, 1987). These terms incorporate alpha, beta, and gamma diversity as traditionally used by ecologists (Whittaker 1975). Conservation strategies should address the range of diversity from the molecular level of genetic material to species and ecosystems. A diversity information system should support the assessment process by providing the data needed to describe current environmental baseline conditions, identify species and habitats at greatest risk, guide land management decisions, and model the effects of alternative conservation policies.

In the past, environmental data were often collected and organized for a single, limited purpose. Further use of these data may require reformatting, or even recollecting. Given the increasing demand for information on the status of biological diversity, many researchers and resource managers are realizing the need for improved information systems (Scott et al, 1987a, Pellew and Harrison, 1988, Mooneyhan 1988, and U.S. Congress Office of Technology Assessment, 1987). Marble (1986) has described a number of the shortcomings of existing species databases (e.g., lack of a consistent data dictionary and update procedures). To accomplish our goal of developing an overall species diversity information system, we must broaden our perspective and consider the overall flow from data capture to analysis and management and not simply the content of the GIS database (Estes, 1985). In the material which follows, the types of data available, how they are typically used in a non-GIS context, and the limitations of that approach are described. Next, we outline a generic information system for integrating data key to the assessment of biological diversity. Although the system is described in the context of a National Center for the United States, the basic concepts could be readily adapted by other nations and institutions. Finally, we propose a process to address one specific component of a conservation program, the search for biotic communities and species in need of preservation management (gap analysis).

2. Background

An idealized set of data for assessing the status and projecting trends in biological diversity include the distribution of taxa, ecological factors that characterize their habitats, and human activities that affect habitats (Table 1). These data are inherently spatial attributes, and thus can be stored in map (or graphic), tabular, and textual format. Here we describe the nature of these attributes, how they are mapped, how they have been used in assessments of biodiversity and conservation planning, and the limitations of those methods, especially when GIS technology has not been used. Table 1 considers only the terrestrial biota, although some of the ideas also apply to aquatic species and ecosystems. We arbitrarily distinguish three levels of spatial scale, recognizing the difference in biological and ecological variables that most influence distribution at each scale. The broadest level is the biogeographic scale and corresponds to areas roughly 10^4 to 10^6 km^2, the magnitude of the range of many species. At the next level down in the hierarchy is the regional scale. A region can be an area ranging from 10^2 to 10^4 km^2, in which the climate type, physiography, and dominant vegetation are relatively uniform. Ranges of subspecies and varieties are often of these dimensions. The local scale applies to homogeneous ecosystems on the order of 10^{-2} to 10^2 km^2 in size, at which distributions of rare species, populations and associated microhabitat factors can be delineated. Integration across scales should be possible, but has been difficult in practice in ecology (Allen and Starr 1982). Translating across scales has not just been a scientific problem but a difficult technical and managerial problem as well. Technically, the issue of multiple representation with a GIS is a significant issue related to this problem. Management of biodiversity must occur at all ecological scales, requiring the cooperation of all jurisdictional levels.

TABLE 1.
TAXONOMIC, ECOLOGICAL AND CULTURAL VARIABLES REQUIRED FOR ASSESSMENT BIOLOGICAL DIVERSITY AND THEIR CORRESPONDING INFORMATION SCALE

INFORMATION SCALE, AREA EXTENT (KM^2) AND SUGGESTED MAP SCALE	TAXON DISTRIBUTION	HABITAT FACTORS	CULTURAL FEATURES
• BIOGEOGRAPHIC • 10^4–10^6 • 1 : 2,500,000 – 1 : 10,000,000	• SPECIES RANGE (HISTORICAL AND MODERN)	• CLIMATE TYPE • PHYSIOGRAPHY • VEGETATION FORMATION • SOIL ORDER	• DOMINANT LAND USE • ADMINISTRATIVE BOUNDARIES
• REGIONAL • 10^2 – 10^4 • 1 : 100,000 – 1 : 250,000	• SPECIES AND SUBSPECIES RANGE (HISTORICAL AND MODERN) • POPULATION OCCURANCES (NOTABLY RARE, ENDANGERED AND INDICATOR SPECIES)	• CLIMATE PROVINCES • LANDFORM • VEGETATION SERIES • SURFACE GEOLOGY • SOIL ORDER • COMMUNITY INTERACTIONS	• LAND USE • PRIME FARMLANDS • LAND CAPABILITY • ENERGY/MINERAL RESOURCES • TRANSPORTATION CORRIDORS • AIR/WATER QUALITY • LAND OWNERSHIP • NATURE RESERVES
• LOCAL • 10^{-2} – 10^2 • 1 : 10,000 – 1 : 100,000	• NARROWLY ENDEMIC SPECIES • POPULATION OCCURANCES • OBSERVATION DATA	• MICROCLIMATE • TOPOGRAPHY • VEGETATION ASSOCIATION • SURFACE GEOLOGY • SOIL TYPES • HYDROGRAPHY • COMMUNITY INTERACTIONS	• LAND USE • ZONING • PRIMARY/SECONDARY ROADS • AIR/WATER QUALITY

2.1. Current Methods and Their Limitations

Several types of assessment of biodiversity have previously been performed, based either on species or communities. One assessment approach is to evaluate the degree to which each vegetation community type has been preserved. For instance, the U.S. Forest Service investigated how well each Bailey ecoregion (1976) is represented in the existing wilderness system as one criterion for recommending new areas for formal designation by Congress (Olson et al 1983). Crumpacker (1988) conducted a GIS analysis of the United States by intersecting Kuchler's potential vegetation map (Kuchler 1964) with Federal and Indian lands. They found many terrestrial and wetland ecosystems under represented on these lands. Basing conservation strategies on potential vegetation should be approached cautiously, however. As Scott et al (1988) observed, disturbed areas such as the prairies in the U.S. Great Plains may never revert to their potential cover, even if agricultural activity ceased. The Crumpacker assessment also begs the question of whether each potential vegetation type on Federal land is actually preserved, since not all agencies manage land specifically to maintain biodiversity. The Nature Conservancy (TNC), which has been a leader in this field, also employs a community-level assessment of preservation status to identify candidate communities for preservation. TNC believes that preserving the best representatives of natural communities, which they refer to as a 'coarse filter' method,can assure the long-term survival of perhaps 85-90% of all species (Noss 1987, Jenkins 1988). Species at greatest risk of extinction, however, may not be found in the representative communities, and common species may be overlooked until they too are in jeopardy.

To overcome this potential oversight, TNC also employs a 'fine filter' method to identify habitats of species that are threatened, endangered, rare, or otherwise of biological interest. Thus, any critical species not protected in the community reserves can be managed individually, but only when their geographic occurrences are known. Species that are relatively common now are not considered, so if the fine filter approach were used exclusively, their habitat could decline from human development. More importantly, until we conduct an unbiased survey of biological diversity at the appropriate level of resolution, we simply do not know what percent of biodiversity is protected nor what remains to be done.

An alternative approach that combines species and community perspectives, involves monitoring a species that is characteristic of a particular habitat, as a measure of the condition of an entire community. An example of such an indicator species is the Spotted Owl (*Strix occidentalis*), used because it is sensitive to disturbance to its old growth conifer forest habitat in the Pacific Northwest (Simberloff 1987). Maintaining adequate habitat for an indicator can presumably preserve all, or at least most, other species dependent on the same habitat.

Simpson (1964) investigated species richness by counting occurrences in very large grid cells from range maps. His initial approach, based on simple visual interpretation of the resulting richness map, has been extended to include quantitative models of ecological relationships (e.g., Richerson and Lum, 1980, Miller et al 1989, in press). Centers of species richness, identified from ranges of small subsets of all species, have occasionally been recommended as nature reserves. For instance, in a gap analysis for Ecuador and Columbia, Terbough and Winter (1983) mapped richness of endemic birds and recommended the richest sites as nature reserves. They explicitly assumed that centers of richness for all other taxa coincide with those of endemic birds. Scott et al (1987b) have demonstrated the power of GIS by comparing species richness of endangered forest birds in Hawaii with existing reserve boundaries. Assessments have seldom, if ever, been based on a systematic survey of all elements of diversity within an entire biogeographic province or political jurisdiction. Instead, the analysis has usually been based on a simplified set of factors, focusing on rarity or usefulness to humanity. Cultural and political considerations have also limited the search to selected areas or species.

These examples illustrate some of the scientific issues confronting researchers and resource managers attempting an assessment of the status and trends of biodiversity. Additional technical issues exist. These issues relate directly to the use of GIS for the assessment of biological diversity. The first is data quality, in terms of low spatial resolution, uneven spatial coverage, currency of dynamic features, and map accuracy. Besides this cartographic uncertainty, ecological relationships of species and habitat requirements are often poorly understood. Another problem is locating and consolidating the large volume of data required and then integrating the various data structures. Sometimes data aggregated to different political and ecological units must be transformed to a common system. Once the data are organized, there is still the problem of manipulating very large numbers of analog or digital map sheets, analyzing their contents, and reducing the results to an effective display. Storage or archiving of these data is also an issue: what data are to be preserved on what media for how long? All too commonly, the next researcher must rebuild the database for a new purpose.

GIS is definitely not a panacea for all these difficulties. Certainly, data in a GIS database can be of no higher quality than the source material. Nor are the data transformation, manipulation, and analysis issues trivial. Map errors, for instance, can propagate and multiply through overlay operations. We maintain, however, that digital GIS can be a more effective approach than either manual methods or non-spatial automated means of making a biodiversity assessment.

3. Conceptual Design of a Biodiversity Information System

As suggested above, information system design involves the articulation of the entire data flow process. The flow of information, diagrammed in Figure 1, includes the five basic components of a GIS:

1) data encoding,
2) data management,
3) data retrieval,
4) data manipulation and analysis, and
5) data display (Smith et al 1987).

The system design described here is meant to be generic, whether in the context of a National Center for Biological Diversity and Environmental Research or an existing agency or organization.

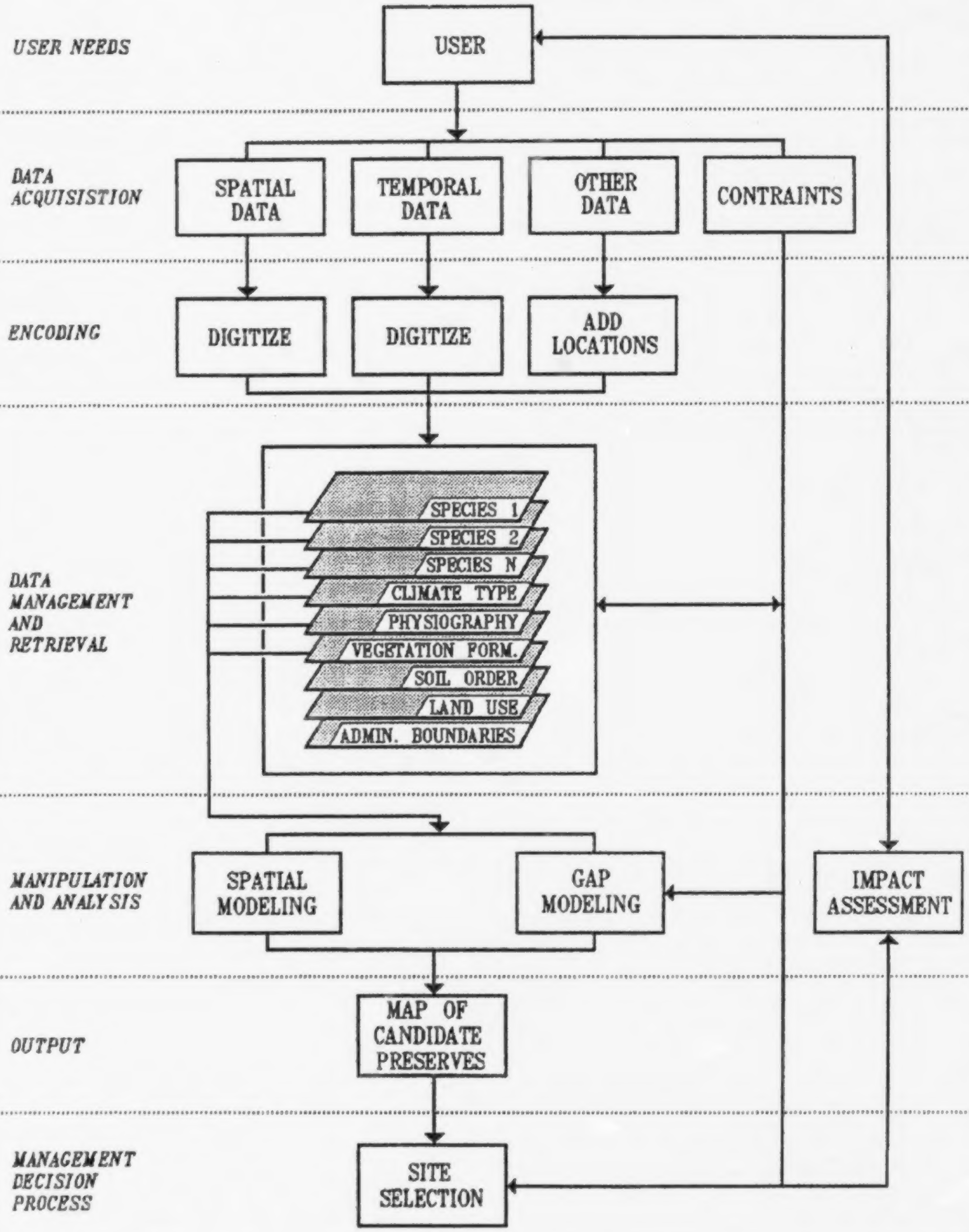
Database construction, including correcting errors and standardizing information, generally requires a substantial investment of resources (Dangermond 1988). It is not enough to simply observe that data need to be digitized. Data on biodiversity come from many sources that may conflict in the way they represent geographical features, e.g., coastlines. Thus, techniques have been developed to improve map accuracy before, during, and after the digitization process. Tabular data may also need to be restructured and related to spatial coordinates.

An effective GIS needs software tools for efficient data management and retrieval. By data management, we include:

1) the ability to support multiple users,
2) efficient data storage, retrieval, and update,
3) nonredundancy of data, and
4) data independence, security, and integrity (Estes, 1986).

The information system must also support the two most fundamental types of database query: what attributes occur

FIGURE 1.
INFORMATION FLOW IN A BIODIVERSITY DATABASE


USER NEEDS
USER
DATA ACQUISISTION
SPATIAL DATA
TEMPORAL DATA
OTHER DATA
CONTRAINTS
ENCODING
DIGITIZE
DIGITIZE
ADD LOCATIONS
DATA MANAGEMENT AND RETRIEVAL
SPECIES 1
SPECIES 2
SPECIES N
CLIMATE TYPE
PHYSIOGRAPHY
VEGETATION FORM.
SOIL ORDER
LAND USE
ADMIN. BOUNDARIES
MANIPULATION AND ANALYSIS
SPATIAL MODELING
GAP MODELING
IMPACT ASSESSMENT
OUTPUT
MAP OF CANDIDATE PRESERVES
MANAGEMENT DECISION PROCESS
SITE SELECTION

at a specific location? and, where do specific attributes occur? (Smith et al 1987) By integrating a relational database management system into the biodiversity GIS, queries on subsets of the data would be possible. For instance, data on all species endemic to a region could be readily accessed and displayed.

The power of GIS comes from its ability to manipulate spatial objects and their attributes to generate new information not explicitly stored in the database. It is beyond our intent to enumerate all analytical operations performed by a GIS (see Smith et al 1987 for a summary), but map overlay, point in polygon, buffer, and area measurement are among the most important functions envisioned for a biodiversity GIS. In addition, the GIS should be capable of shipping data to analytical models used by ecologists, biologists, and natural resource managers, and then re-importing the model outputs for display as maps, tables, or graphs (Dangermond 1989). Whereas the direction of information flow runs from input to output (Figure 1), the system design process should begin with the information products that users expect from the GIS, and then work backwards to the source data requirements.

3.1 User Needs and Information Products

An important initial phase in the design of an information system is to identify that set of users to be supported and to assess their information needs. Often the calls for a biodiversity assessment have not been very specific as to the form of its outputs. Would it generate a map of species richness, or of conservation 'hot spots', i.e., biologically significant areas facing imminent degradation? Or lists of species and biotic communities in decline? Would the database be continuously queried interactively by users or only used periodically for major updates of the assessment? A formal user needs assessment should be performed prior to any database development. Consequently, the discussion that follows should be viewed as preliminary, based on our experience with the biodiversity issue to date. Potential users of the proposed information system would certainly include public policy makers, natural resource managers, research scientists, conservation organizations, natural resource industries and public utilities, international development organizations, and educators. Multiple uses of a small scale biodiversity GIS database help justify the massive effort required to construct it (e.g., Cocks et al 1988). On the other hand, satisfying a complex set of users needs is generally more difficult than with single- purpose databases (Rhind and Green 1988).

A biodiversity information system should address the following kinds of questions:

- what is the range of a given species or community type?
- which species are at greatest risk?
- which sites have greatest species richness?
- which biologically important sites are at greatest risk
- which ecosystems are adequately protected?
- what environmental factors are related to the sites of greatest biodiversity?
- can diversity be predicted on the basis of these factors?
- where can ecologically sustainable development occur with acceptable impacts on biodiversity?
- what are the trends over time in species and ecosystem diversity?

Each of these questions represents a specific user need. In the aggregate, these needs must be taken into account in designing a GIS to address issues related to the preservation of biological diversity.

3.2 Database Applications and Functions

Based on our preliminary user needs assessment, we have identified four primary applications of a biodiversity information system: the baseline assessment of biodiversity and subsequent updates, identification of gaps in the nature reserve network, environmental impact assessment of proposed development projects, and a wide range of scientific research. These applications are described briefly in the following paragraphs, including the data retrieval and analysis functions needed to perform them.

3.2.1. Biodiversity Assessment

The fundamental assessment would consist of several components. The manual overlay method of determining species richness (e.g., Simpson 1964) could be automated. Range maps can be refined by incorporating data about the distribution of habitat factors. Area of communities is automatically computed, which can be use to identify rare types. Both the species richness map and vegetation map could be compared to maps of existing land use and land suitability to determine the extent of current and potential loss of biodiversity. Where land suitability maps do not exist, GIS methods have been effectively used to derive them for many resources based upon the relationships of mapped environmental variables (Dangermond 1989). The objective of this application is to produce a map of the spatial location of the richest and rarest components of biodiversity and an indication of which are at greatest risk.

Of particular concern, especially in lesser developed nations, is the lack of primary biological data. GIS can also be used in such situations for sample design. One approach is to analyze the degree of uncertainty, say in a species richness map, as a function of spatial location. Sites with greatest uncertainty are the highest priority for field sampling. Alternatively, if the relationship between richness and ecological factors is known, modeling can predict where richness is likely to be greatest, and thus, where surveys are most urgently needed.

3.2.2. Conservation Gap Analysis

One widely used strategy for preserving biological diversity is to allocate lands for nature reserves. Some sites are managed exclusively for preservation and research, while public recreation and low intensity resource utilization are permitted on others, depending on the mission of the responsible agency or organization. Candidate sites for new reserves can be identified and evaluated by some form of 'gap analysis' (Scott et al 1988), that identifies species or habitats not permanently preserved from human impact. The output of a gap analysis is a map of candidate sites of high conservation value and tables of communities not currently represented (or under represented) in a preserve network. Diversity elements not found in reserves face greater risk of extinction, and thus represent gaps in the conservation strategy. A process to identify gaps in the network of reserves is discussed in Scott et al (1988) and in Section 4 of this paper.

3.2.3. Impacts of Proposed Developments

An important use of a national biodiversity information system would be to aid in the evaluation of the effects on biological diversity in the environmental impact assessment process and any subsequent attempts at mitigation. The information system can be the point of contact for data on critical elements of diversity that may be impacted by a given project. This transaction involves overlaying the project boundaries with the data layers of endangered species observations, species richness, and communities, resulting in a map of locations of critical elements of diversity potentially affected.

3.2.4. Scientific Research

A comprehensive biodiversity information system would be an invaluable asset to scientific researchers, whose time could be spent analyzing data and testing theories, rather than locating, verifying, and reformatting data. To enhance the accessibility to the data maintained within the system, we suggest a computerized directory of data sources and nature reserves, similar to one for digital satellite data under development by the U. S. National Aeronautic and Space Administration (Estes and Bredekamp 1988).

Research, by its nature, involves exploration of new methods of data analysis, including spatial analysis functions, making it difficult to design an information system (Rhind and Green 1988). Rather than attempting an exhaustive enumeration of the potential roles for GIS in biodiversity research, here we suggest a few potential applications.

Optimal conservation strategies for selecting sites for reserves and establishing boundaries have been an ongoing theoretical issue for many years (e.g., MacArthur and Wilson 1967, Zimmerman and Bierregaard 1986). It is beyond our intent to elaborate on this debate here. However, many of the variables involve size of habitat 'islands' in disturbed landscapes and distance between them or the association of ecological factors. GIS, as discussed above, is adept at analysis of spatial and multivariate properties.

GIS can also provide data management and display capabilities for ecological modeling. Predictive modeling of species ranges has been described above. In addition, researchers are using spatial data to explore issues of global change and its effects on biodiversity. Examples include projecting future distributions of species and communities under the Greenhouse Effect (Busby 1988) and future levels of land use activities (Esser 1989).

3.3 Database Contents

Based upon the preceding discussion of user needs and GIS applications, we can now tentatively identify the data inputs to a national biodiversity assessment. Even though having all of the factors listed in Table 1 would be the ideal, as a practical matter, priorities must be set for the sequence of data encoding. The most urgently needed data layers, we suggest, are:

1. Existing range maps for vertebrate species.
2. Ecoregions map, integrating many habitat factors.
3. Map of large nature reserves, e.g., wilderness areas.
4. Sites of rare and endangered species and communities.
5. Major human land uses and potential land conversions, e.g., for energy and mineral development.

For the initial assessment, these data would be assembled at a small scale. Over time, as museum and herbaria collections become computerized, as range maps are revised through more current observations, as remotely sensed imagery is used to record recent land use changes, and so on, the database can be refined and magnified in scale.

The authors believe that a National Center should not attempt to be the repository for all biological data, but instead should implement a central directory while planning for a distributed database system over the longer term. This recommendation is consistent with that of the National Academy of Sciences (Committee on Data Management and Computation 1986), which endorses the concept of networked distributed data centers with the data residing in close proximity to the most active user community.

3.4 Development of Standards

A data dictionary is the vehicle for establishing standards for the contents of the database and documenting their definitions and attributes (Marble 1986). Other aspects of the definitions include their source, resolution, standardized geographic coordinate system (for spatial data), their required quality, precision, and legitimacy (objectivity, reproducibility, accuracy, and authority), the definitions of each variable and its legitimate values, and the schedule for updates or revisions. Too often, a dictionary is not formally prepared, leaving system users with datasets of unknown origin and relevance.

Although it is known that data coverage is not uniform for all species and habitats and for all geographic regions in the USA, no systematic survey of existing biodiversity datasets has ever been made (Tangley 1985). Creating the data dictionary systematically determines which datasets, meeting the required standards, already exist, and which must still be collected. The GIS database design process naturally forms the basis for a first comprehensive assessment of the biodiversity knowledge base.

4. The Process of Conservation Gap Analysis Process

In this section, we examine one of the most complex applications in a biodiversity information system, gap analysis, in greater detail. Scott et al (1988) have previously outlined the basic procedure and discussed the biological rationale. Here we demonstrate the feasibility of this procedure by verifying that the required data and GIS functions are typically available. For illustration, we have chosen the State of California, USA, where a pilot analysis is being contemplated (Kent Smith, 1989).

California, covering approximately 411 000 square kilometers, is an extremely heterogeneous environment, hosting a diverse flora and fauna in five biogeographic provinces (Udvardy 1975). Although 11% of the State is already under some form of preservation management, many important habitats and species are still not adequately protected (Klubnikin 1980). Experts estimate that 220 animal and 600 plant species and 200 natural community types are experiencing severe reduction or facing extinction in California (Jones and Stokes Associates 1987).

Three biodiversity components of a gap analysis include geographic centers of species richness of animals, habitats of all special interest species and endangered communities, and representatives of all vegetation communities. Tentative sources of data to be used in the California gap analysis are listed in Table 2. We suggest that an acceptable first approximation of species richness could be determined by overlaying range maps of approximately 700 vertebrates (i.e., mammals, birds, fish, reptiles, and amphibians), recently updated and digitized by the California Department of Fish & Game (CDF&G) at a scale of approximately 1:3 400 000. Ongoing gap analysis programs in Idaho and Oregon have produced range maps by masking out land use categories and vegetation types that are not used by the species (Blair Csuti, 1989). Ranges of the 5 000 native vascular plants and 28 000 insect species that inhabit the State are less well known than the vertebrates, and are not recommended for gap analysis. Butterflies were also recommended by Scott et al (1988) as representatives of invertebrates, but maps of their ranges are not yet available for California.

The locations of populations of nearly 1 100 rare, threatened, endangered, and special interest species and communities are available in digital format in the Natural Diversity Data Base (NDDB) of the CDF & G (Jones and Stokes Associates 1987). Because the NDDB is not a GIS, the specimen locations must be reformatted into the GIS data structure. Known locations of rare and endangered species can be supplemented by predictive modeling of species range or richness from ecological variables, including climate, topography, vegetation, soils, and geology. Habitat factors known to produce rare and unusual species, such as vernal pools or serpentine soils (Jones and Stokes Associates 1987) could also be used to delineate biologically significant areas. The vegetation layer is needed both for modeling and to portray vegetation communities as the third component of the gap analysis. Only one map of actual vegetation currently exists for the entire state at an appropriate scale, the CALVEG map produced by the U.S. Forest Service (Matyas and Parker 1980).

A map depicting the boundaries of existing nature reserves, both public and private, is needed to identify species and ecosystems already protected. Defining what land management constitutes preservation may be politically sensitive, since a management prescription may preserve some species and not others. The data dictionary described earlier must establish clear criteria as to what areas are to be included. A preliminary selection of sites that qualify as nature reserves includes Federal research natural and wilderness areas, national parks and wildlife refuges, state parks and reserves, the 27 sites of the University of California Natural Reserve System, and lands owned or leased by

TABLE 2.
DATA LAYERS REQUIRED TO IDENTIFY GAPS IN THE RESERVE NETWORK IN CALIFORNIA

DATA CATEGORY	DATA SOURCE	PUBLISHED SCALE
BIOGEOGRAPHIC PROVINCES	UVARDY (1975)	1:50 MILLION
VERTEBRATE RANGE MAPS	CALIFORNIA DF&G	1:3.4 MILLION
SPECIAL INTEREST SPECIES AND COMMUNITIES	CALIFORNIA DF&G (NDDB)	TABULAR
ECOLOGICAL FACTORS		
CLIMATE	VARIOUS	VARIOUS
ELEVATION	USGS *	1 : 250,000
VEGETATION ASSOCIATIONS	CALVEG	1 : 250,000
GEOLOGY	CAL. DIVISION OF MINES	1 : 250,000
SOIL ASSOCIATIONS	USDA SCS **	1 : 250,000
EXISTING RESERVES	VARIOUS	VARIOUS

- * *U.S. GEOLOGICAL SURVEY*
- ** *U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE*

TNC and other private conservation groups. Although state and national parks are included in this initial list, their primary mission is to preserve outstanding scenic and recreational areas, and thus do not meet the definition offered in Section 2. Park areas outside of developed recreation facilities, however, often preserve natural ecosystems and should be considered in this inventory. Regional parks perhaps should also be considered.

The original data will not be in a form where gaps in the reserve network can be easily detected. Part of the challenge is integrating small scale species range data (e.g., 1:3 400 000) with medium scale maps of vegetation communities and rare and endangered species (e.g., 1:250 000). Species richness will be derived by overlaying the vertebrate range maps and then be stratified by the map of biogeographic provinces (e.g., Udvardy 1975) to identify centers of greatest richness. It would be naive to think that a GIS-based gap analysis would precisely identify areas of high species richness, because small scale range maps are inherently crude representations of the area actually occupied by species. At best, a map of vertebrate species richness could indicate sites that should be investigated in greater detail. Manual methods of gap analysis would be prone to these same problems, but would be extremely tedious in comparison to a digital GIS approach.

Known and modeled locations of all special interest species and natural communities from the NDDB would be composited for the State and intersected with the map of centers of species richness and the map of existing nature reserves. Biologically rich areas and special interest areas outside of existing reserves would be candidates for designation as new nature reserves.

The map of existing nature reserves would next be compared with the CALVEG maps of vegetation associations, quantifying the area of each association within reserves and identify communities that are preserved nowhere or only rarely, in the State. Determining the extent to which vegetation communities are represented in the preserve network is probably most effectively done by examining a tabular listing. From such a table, priorities can be set for the most critical community types and a search of the GIS database for the best examples of each type can be initiated.

Conducting a comprehensive gap analysis as described here is clearly an ambitious undertaking. It appears technically feasible to do, however, for an area like California, where reasonably good quality data already exists. Data volume is large but not beyond the capacity of a modern minicomputer disk drive. As a rough approximation for our example, we estimate 750 data layers, most of which are species range maps, and could therefore be simple bit maps. Even using a raster data structure, with 1 square kilometer cells, 1 byte per cell, the data volume for California would be on the order of 300 megabytes, which could be significantly reduced with a more efficient data structure or lower resolution. Gap analysis primarily involves overlay, reclassification, and topographic functions that are all routine capabilities in most commercial GIS's. Even modeling is possible with a GIS database (e.g., Miller et al 1989 in press). For a gap analysis to be accepted by decision makers, the issues of cartographic error and its propagation through the analysis process must be addressed. The species richness map and model predictions must be validated with field data. The analysis procedure must also overcome the implicit assumption of preservation management that species ranges are static. Concerns have recently grown, for instance, about the potential impacts on nature reserves and their resident species if the Greenhouse Effect occurs (Peters and Darling 1985).

5. Conclusions

Although a comprehensive assessment of the trend of biological diversity has been beyond the capabilities of the scientific community, case studies from around the world show that diversity is being reduced at a disturbing rate. To formulate biologically defensible responses to this crisis, we must garner the best data we have on species, their habitats, and human land uses that affect habitats. Many efforts to collect and manage data on biological diversity are underway (e.g., TNC's Heritage Data Base program, International Union for the Conservation of Nature's Conservation Monitoring Centre) or under discussion (e.g., the National Center for Biological Diversity and Environmental Research proposed in H.R. 4335).

In this paper, we have proposed a concept for a comprehensive diversity information system that builds on this strong foundation. The conceptual information system we propose, based on a GIS approach, is integrative in three important ways. First, data from many disciplines are brought together in a single database, essentially for the first time. This contrasts with existing databases which are typically structured around a single theme or a small subset of biological species. Bringing together data on the distribution of areas of high biological interest and sensitivity with data on potential resource development can encourage a pro-active rather than a reactive approach to resolving conflicts. Because the data needed by a diversity information system overlaps with the needs of a wide variety of resource management agencies, horizontal integration across departmental lines is also imperative. The difficulties in obtaining agreement between the players on the data dictionary and other issues is acknowledged. However, there seems to be a growing acceptance within the U.S. Federal establishment of the need for interagency coordination in data management. Second, the system encourages the vertical flow of spatially distributed information. Data from lower levels can be aggregated and generalized for use at higher levels, which in turn, can serve as clearinghouses to disseminate information about gaps in data and reserves and about experience in other jurisdictions. Third, the system could provide information to a wide variety of users, including policy makers, development interests, researchers, and the public. We predict that the directory function will be especially useful to persons trying to locate data.

We have specifically outlined this information system in the context of a National Center for the United States, as stated in H.R. 4335. Similarly, our proposed process for conservation gap analysis is for the State of California, and is based on ecological factors and datasets specific to the area. However, as stated by Scott et al (1987a, 1988), the system concept presented and the process involved in development and the functions of the system are generic enough to be adapted to the needs of other nations and states. It is recognized that lesser developed countries will be the most hampered in their database development, due to the lack of data and of the infrastructure to maintain advanced information systems. Indeed, all nations will be confronted by a combination of cartographic uncertainty of their primary data and ecological uncertainty about the relationships between biodiversity and environmental factors. Through pilot studies, these relationships can be better understood. From environmental maps, nations can begin to systematically determine priorities for field surveys and for conserving their natural heritage while developing their resources. Leon et al (1985) observed that no database in and of itself has saved a single species, at least in the case of Mediterranean plants, to which they were referring. Information systems make no guarantee they will be used to make wise decisions. However, we have all seen the price paid for decisions made without good information, species after species have been driven to extinction by both willful and inadvertent human disruption of critical habitat, or species which were saved only through heroic and expensive recovery programs. If the quality of land use decisions can be improved by incorporating a better understanding of the location of the important elements of diversity and of our effects upon them, we may succeed at ecologically sustainable development of the biosphere.

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Human Encroachment on Bear Habitat

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Abstract

As New England becomes increasingly congested, more and more black bear(*Ursus Americanus*) habitat is being lost or fragmented. The University of Massachusetts, in conjunction with state wildlife agencies, has been doing research on the bears since 1970. Numerous graduate students, researchers, biologists and technicians have garnered a vast amount of information in the past twenty years, which is now being combined into a single data base using GIS. Blending historical data and current research findings for trend analysis has been started with GIS.

Introduction

The black bear population of western Massachusetts has shown considerable fluctuations since the arrival of European man. Land use alterations have had as significant an impact on the bear as exploitation at the hands of man.

The settlers quickly took to the task of clearing and converting the land to agricultural uses. At one point, approximately 75% of the land was opened in this way. The legacy of stone walls, painfully created by hand, marches across the face of the New England landscape as a reminder of that time. Deforestation, coupled with heavy exploitation, all but eradicated the bruin from Massachusetts. With definite vermin status on his head, the war against the bear was all but won, and might have stayed that way, if not for the gradual change in land use returning to a forested expanse once more.

Sightings and rare bear-human conflicts began to occur once more at the beginning of this century (Cardoza 1976). Thousands of acres were once more in mature or successional forest stages, allowing for the cover and food needs of the black bear. Practising high avoidance behavior, the bear began to rebuild its numbers slowly.

Over the next 80 years, a small founder population expanded to the current population estimate of 750 black bears in western Massachusetts (work in progress). Unfortunately for the bears, the human population was also growing, and in numbers incompatible with bear habitat. Land use changes have begun again to have an affect on the bears, and now those changes are more likely than ever before to be permanent. Fragmentation is increasingly a pressing constraint to habitat. Assessing these changes and their impact on the bears has been the focus of research and is the focus of this paper.

Study Area

The main site of research is the land west of the Connecticut River to the New York boundary. Connecticut forms the southern boundary and the northern boundary is formed where Massachusetts meets Vermont and New Hampshire. The land varies from lowland agriculture to the wooded and remote Berkshires. The forest types range from the northern hardwood mixed forests to transitional forest stands. The land use practices range from towns like Sandisfield, which is 92% forested (MacConnell 1972,1988) with only 750 residents, to cities such as Northampton, which are nearly an urban sprawl. Both types have bears at different densities.

Methodology

Data has been collected from many varying sources. Historical data was obtained from painstaking searches of newspapers, library publications and division reports. Since 1980, telemetry work has been used to monitor bear activity, establish habitat needs, generate population densities and to begin to identify corridor and critical habitat needs. The volume of data was overwhelming at first, but slowly order has begun to emerge, and useful patterns have been identified.

Putting everything into a meaningful GIS system has been a challenge, and still much work lies ahead. The first step was to convert much of the data into formats compatible with ARC/INFO. The telemetry data was converted from Telem, a system of using UTM coordinates. The land use cover type maps were all in State Plane coordinates, and required conversion to UTM to match up with the telemetry data. Bear locations were obtained through triangulation in the field and plotted on acetate overlays on USGS topographical maps.

The X- and Y- coordinates were made into tables from which points could be generated to formulate maps. Cover type maps were limited to very basic classifications and required field work to identify the areas critical to black bear habitat. Oak, beech and hickory stands needed to be known, as well as wooded wetlands. Wooded wetlands are particularly critical as spring food sources, and are used throughout the summer and fall also. The bears time their emergence from hibernation to match the bounty of skunk cabbage and tubers that are prolific only in wooded wetlands.

The other areas that needed identification were travel ways. Corridor studies are current research in many fields and little has been done for quadrupeds in New England to compare our data with. Bears, like many animals, will use the same travel ways that other animals and bears use. These trails tend to be along riparian settings, but some have been noted to use ridges. To verify existing travel ways, a search was conducted to identify road kill sites and culvert usages for confirmation. Using GIS, these areas could easily be mapped and assessed for patterns and locations. The data did reveal certain vulnerable sites where up to five bears had been mortally injured over the past twenty years, all within feet of each other. An increase in the number of vehicular incidents proved to be on the rise. The bear population is growing, but so are the number of roads and cars.

Telemetry data gives a more individualized picture of the bears. Each bear takes on its own personality. Whether that is good or bad, it forces the realization that they cannot be lumped into one type of behavior for a given set of criteria. Generalities can be made but there may be exceptions to the rule. Beehive raiding is one example. As opposed to popular opinion, at least for the bears in this study area, not very many bears go after farmer's hives (Elowe 1984,1987). Prime young males (five to six year olds) are the usual offenders, though the occasional sow may be caught, but the majority will walk right past a hive. This may be avoidance of human contact, or just that they weren't taught by their mothers to raid hives. This would make it difficult to predict for a bee keeper if his hives were in danger. The bears in his area might not be interested. Corn, on the other hand, will be depredated, especially during poor mast years, by most bears. Many bears taken in nuisance control will be due to efforts to save corn fields.

These inconsistencies between bears is what has made GIS an ideal tool for mapping bear ranges. No territorial behavior has been noted in the past among the telemetry bears. In fact, three sows, each with cubs, have been observed in the same wooded wetland within two hundred feet of each other. They carefully ignore each other in these circumstances. The various ranges, the amount they overlap, and degree of shift is easily analyzed with GIS. Males have an average home range of 150 square miles. It is far easier to map this size range into a flexible mapping system. When June rolls around and a young bear's heart turns to fancy (so to speak), they can make large digressions outside of their usual range in search of female company. This ensures genetic variability, as the male will probably not mate with close relations in this way. These forays have not been well documented, due to the difficulty of monitoring bears movements over great distances. Dispersing young males have been removed from the primary research site study data in the past, since monitoring one male many miles away from the main research site was not productive for research goals. GIS will enable this information to be collected in the future, and dispersal trends may emerge. Now that a format is available that can take all the data that was too vast in the past, or not relevant to the study, it will be much easier to save data that may prove very useful down the road.

Results

Research has shown range sizes, habitat preferences and needs, and population dynamics (Elowe 1984,1987). The conversion to GIS has enabled this data to be updated and to act as a central reference system for all the information. Generating home ranges and combining these with known habitat and cover maps, shows the most critical locations. Updating this information has shown some bears to shift as habitats vanish, while others may try to stay in smaller and smaller parcels. Some older males seem very reluctant to leave a choice wetland, in fact, one is living within a stones throw of a bar in a small (three acre) wetland that is totally surrounded by a two year-old development. To his credit, he's only been seen by the residents once or twice. This is where the exception is apparent, but most bears, if they move off, do seem to go to less developed areas than those they were in.

Some of the radio-collared bears have used roads as loose range boundaries, while others will regularly cross very busy paved roads. On examination of range size changes from year to year, bears will expand or shift their ranges during years of shifting food supplies. If there is a bad mast year, they may add a farmer's field into their wanderings, if it is not too far from their regular range. By examining these alterations in range, it may be possible to predict where the bears may prefer to be, depending on the food source availability.

In examining density numbers, a population estimate for a core area is first obtained by trying to capture and collar all the resident bears in that area. From this, a density of one bear to seven square kilometers (Elowe 1986) was obtained. Another core area study has been begun this past year that appears to have slightly higher densities, as the habitat is more suitable for bears, and the location is freer of people. Taking the amount of potentially available habitat, presuming that the bears can tolerate the densities they are presently at, the area of western Massachusetts could contain around one thousand bears. Whether this is anywhere near the carrying capacity for the population is not known, though it is likely a low estimate based on habitat availability. It is most likely near the biological carrying capacity, or the numbers that will be tolerated by the human population of the same area. Depredation reports have increased and road kills are up from the rare events of twenty years ago, to a reported average of five per year (.7% of the population). Sightings occur in every town, and the harvest mortality rate has steadily risen to an average of 26 bears during the two week season (3.6% of the population).

Conclusion

Using GIS as the data base for an integrated system, management has a tool for making decisions regarding the black bear population. When development activity is anticipated, the cover type maps can be consulted to assess the impact that may be felt by the bear. Alternate sites can be suggested if deemed necessary. In the event of a severely poor mast year, or a major change in the habitat composition occurs from some hundred-year disaster such as a hurricane, the damage to the bear can be studied immediately and remedial steps taken.

Population estimates based on habitat can be generated annually to help determine what harvest rates to set. Other mortality rates can be added, as well as the other population parameters that control the growth rates.

Corridor delineation is a current project for an anticipated major development. Current routes of travel can be defined as they have been for the earlier research sites. Buffer capabilities using GIS make this quite simple, as soon as the travel route is established.

This research is still in the early stages, and is anticipated to be an ongoing process. Presently, it is confirmed that the bear is being set back by human encroachment. Creating a simplified Leslie matrix for the past and current growth rates, it is seen that the bears are probably still increasing slowly, despite harvest and other mortality factors, primarily due to the fact that they are not yet at densities that overstress the habitat.

A GIS data base, using cover type as the base, and telemetry data as one overlay, adding other information, such as den location, road kill sites, etc., as other overlays allows management to look at as many factors as are necessary to keep a healthy bear population. Adding buffer zones around travel routes, and highlighting critical habitats can give wildlife managers an edge when trying to decide on potential development strategies. Where the possibility exists of creating forest stands with the bear in mind, species of particular use to bears can be assessed as to their abundance, and encouraged by regeneration.

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Using GIS for Habitat Management in the Wake of Hurricane Hugo

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Abstract
Hurricane Hugo did extensive damage to the Francis Marion National Forest in South Carolina. Approximately 100 000 acres of forest were leveled causing a variety of environmental problems, including destruction of one of the best habitats in the world for the red-cockaded woodpecker. This paper demonstrates how GIS helped assess the damage and develop specific plans for recovery after the disaster. This included alternative developments, selection of the preferred alternative and estimation of the workload and costs involved. Finally, the GIS provided the capability to share the specifics of the recovery plan with Forest Service personnel, other government agencies and the public.

Background

On September 22-23, 1989, Hurricane Hugo came inland from the coast across the 250 000 acre Francis Marion National Forest, 30 miles northeast of Charleston, South Carolina. Wind speeds exceeded 135 miles per hour and a fifteen foot tidal surge hit near McClellanville, S.C.

Widespread timber damage occurred through the national forest and the surrounding area. In the national forest alone, it is estimated that 700 million to 1 billion board feet of timber were damaged or lost. The storm broke many of the trees, greatly reducing the quality and volume of timber that could be salvaged. Statewide damage from Hugo was estimated to be 6.5 billion board feet.

A decision was made on October 5, 1989, by Forest Supervisor Donald Eng to salvage 250 million board feet of storm damaged timber on the Francis Marion National Forest to assist in recovering and protecting the remaining habitat of the endangered red-cockaded woodpecker, and to decrease potential fire, insect and disease problems.

The salvage effort was anticipated to include immediate local use, export and storage of damaged timber. The storage objective came out of a recommendation by the South Carolina Governor's Timber Disaster Salvage Council, consisting of members from federal, state, local, industry, and academic organizations.

A Log Storage Feasibility Study (Ryburn, et al 1989) indicated that more storm damaged timber was initially available for harvesting and manufacture than area facilities had the capacity to process. The log storage study identified various log storage methods which could be used. As a result of this study, another environmental assessment was prepared which documents the analysis of the range of alternatives to store up to 40 million board feet of storm damaged sawtimber in order to keep the timber merchantable for up to two years and to prevent a localized glut on the market.

The harvest of timber, associated with storage of timber, would further augment recovery and protection issues related to Protected, Endangered, Threatened and Sensitive species of wildlife, particularly the red-cockaded woodpecker habitat and colony sites, the decreased wildfire and bark beetle hazards, smoothing economic impacts on the local forest industry, assist in community stability and to improve conditions for reforestation. These objectives were further developed from issues identified by the interdisciplinary team preparing the storage environmental assessment. Subsequently, several alternatives for action were developed from these objectives. Each alternative was evaluated relative to cultural resources, wildlife, environmental consequences, economic and social factors.

The timing of the salvage harvest is critical. It was estimated that sawlogs harvested after April 1990 would be sufficiently degraded by insects and fungus that opportunities to utilize them for high-valued products would be lost.

Francis Marion National Forest

The Francis Marion National Forest is located in the coastal plain of South Carolina (Figure 1) approximately 30 miles northeast of Charleston. The forest has two districts, the Wambaw and the Witherbee, located in McClellanville and Moncks Corner respectively. Today, most of the 250 000 acres are forested primarily with pine but virtually the entire area has been logged and was at one time farmed. Longleaf pine is the most valuable forest type and is suited best for the well drained upland areas. Loblolly pine is the second most valuable forest type and tolerates less well drained soils. Mature (45 ears or greater) longleaf stands with low or little understory are common and are the preferred stands for colonies of red-cockaded woodpeckers, which are an endangered species. This forest is known as one of the finest habitats existing for these woodpeckers. There were approximately 480 active colonies on the forest before Hurricane Hugo. Other forest types include bottomland hardwoods, swamp chestnut-oak, and cherrybark-oak complexes (Figure 2). A large part of the national forest is non-forested wetland including titi and pond pine. Some areas are also tidal. There are four designated wilderness areas in the forest which comprise approximately 14 000 acres and are mostly cypress, tupelo, and maples.

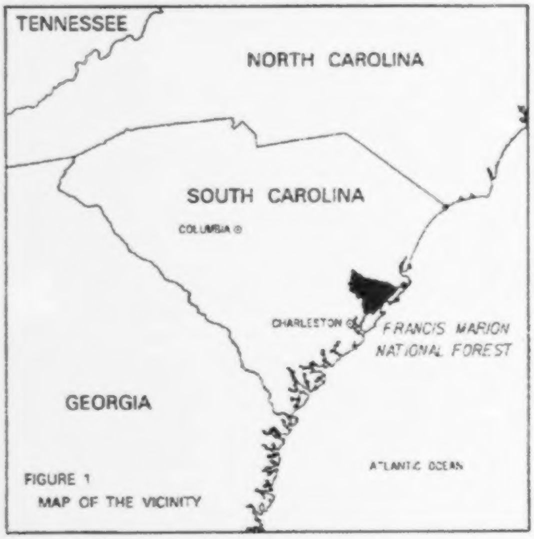


FIGURE 1
MAP OF THE VICINITY

The GIS Database

The GIS data base was designed before the hurricane, and was built to serve the information needs for general management of the forest. More than a year before the hurricane, the staff of the two districts of Francis Marion participated in an Information Needs Analysis which identified the map products they wanted to make. Subsequently, the data layers needed to make these products were identified. The Forest staff prepared the maps for digitizing following the guidelines given in the Region's GIS Implementation Plan. The layers included: Forest Service ownership boundary, lakes and streams, roads and trails, compartments and stands, and archeological sites. Also included were the silvicultural data for each stand, such as, birth date, site

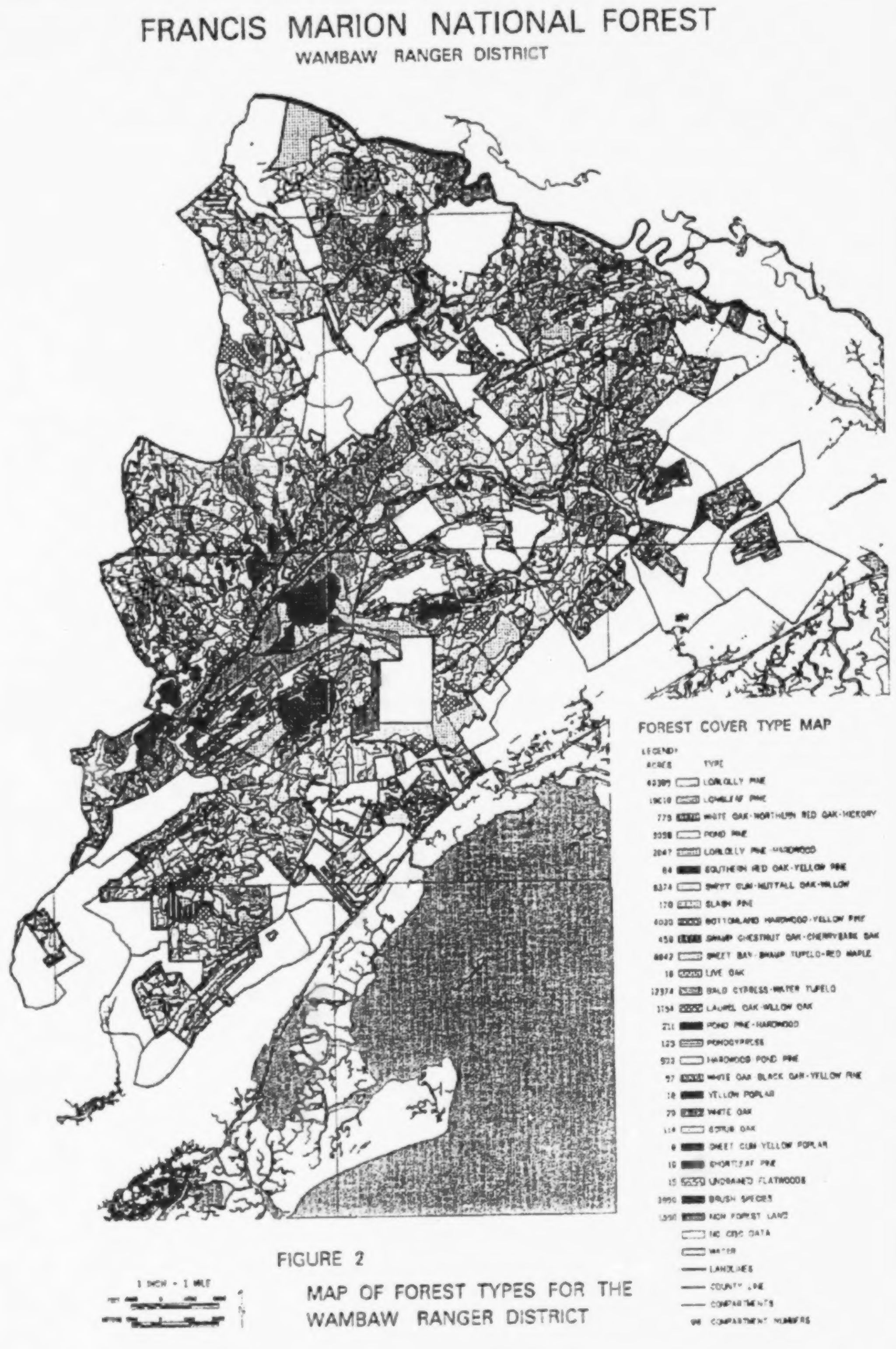

FRANCIS MARION NATIONAL FOREST
WAMBAW RANGER DISTRICT
FOREST COVER TYPE MAP
LEGEND:
ACRES TYPE
63309 LOBLOLLY PINE
19610 LONGLEAF PINE
775 WHITE OAK-NORTHERN RED OAK-HICKORY
9058 POND PINE
2047 LOBLOLLY PINE-HARDWOOD
64 SOUTHERN RED OAK-YELLOW PINE
8374 SWEET GUM-NUTTALL OAK-WILLOW
170 SLASH PINE
4020 BOTTOMLAND HARDWOOD-YELLOW PINE
458 SWAMP CHESTNUT OAK-CHERRYBARK OAK
8842 SWEET BAY-SWAMP TUPELO-RED MAPLE
18 LIVE OAK
12374 BALD CYPRESS-WATER TUPELO
3754 LAUREL OAK-WILLOW OAK
211 POND PINE-HARDWOOD
123 PONDCYPRESS
522 HARDWOOD POND PINE
97 WHITE OAK-BLACK OAK-YELLOW PINE
18 YELLOW POPLAR
79 WHITE OAK
114 SCRUB OAK
6 SWEET GUM-YELLOW POPLAR
10 SHORTLEAF PINE
15 UNDRAINED FLATWOODS
3950 BRUSH SPECIES
1390 NON FOREST LAND
NO CISC DATA
WATER
LANDLINES
COUNTY LINE
COMPARTMENTS
98 COMPARTMENT NUMBERS
1 INCH = 1 MILE

FIGURE 2

MAP OF FOREST TYPES FOR THE WAMBAW RANGER DISTRICT

FRANCIS MARION NATIONAL FOREST
WAMBAW RANGER DISTRICT

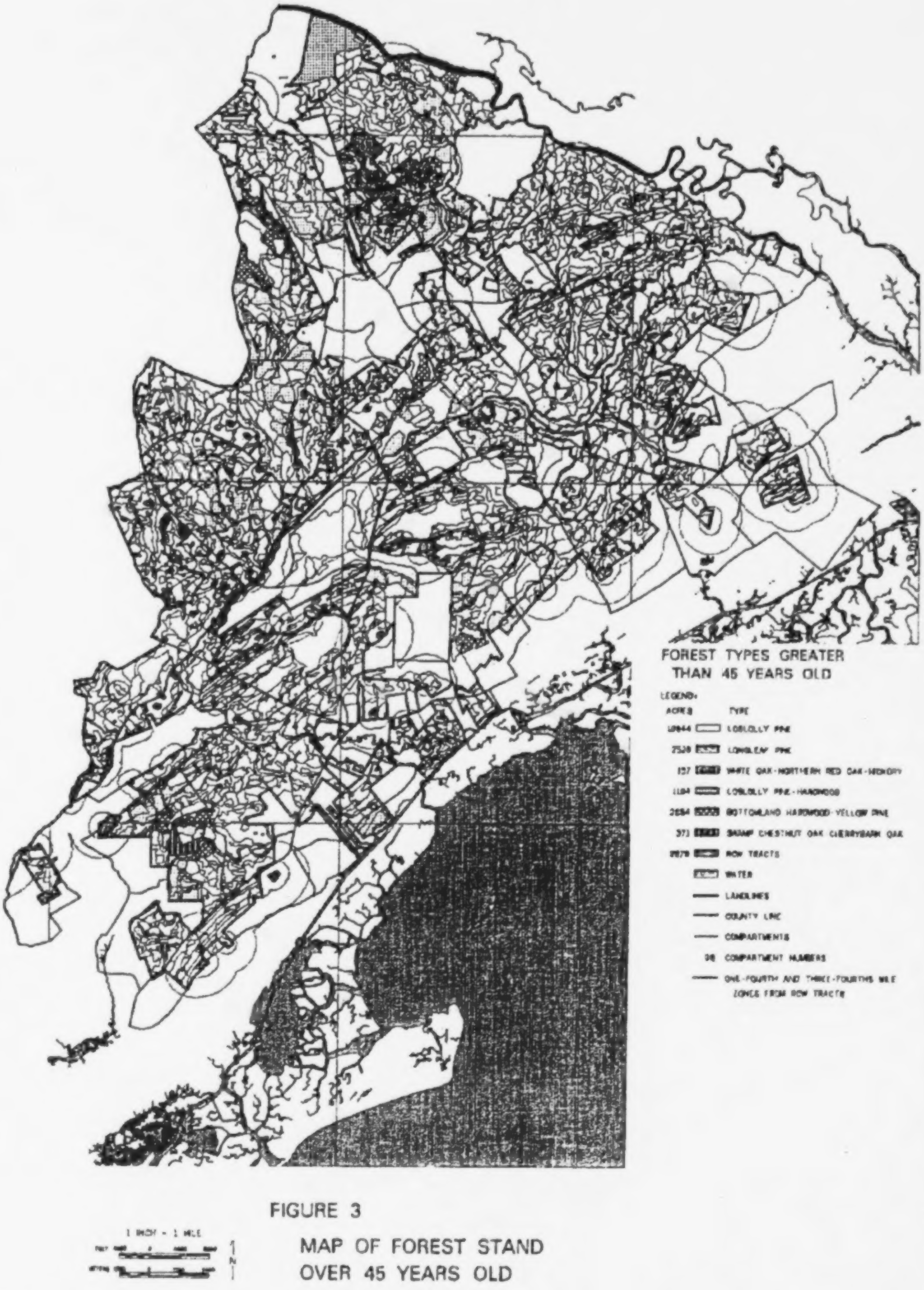

FOREST TYPES GREATER THAN 45 YEARS OLD
LEGEND:
ACRES TYPE
12644 LOBLOLLY PINE
7520 LONGLEAF PINE
137 WHITE OAK-NORTHERN RED OAK-HICKORY
1184 LOBLOLLY PINE-HARDWOOD
2684 BOTTOMLAND HARDWOOD-YELLOW PINE
373 SWAMP CHESTNUT OAK CHERRYBARK OAK
8878 ROW TRACTS
WATER
LANDLINES
COUNTY LINE
COMPARTMENTS
98 COMPARTMENT NUMBERS
ONE-FOURTH AND THREE-FOURTHS MILE ZONES FROM ROW TRACTS
1 INCH = 1 MILE
N

FIGURE 3

MAP OF FOREST STAND
OVER 45 YEARS OLD

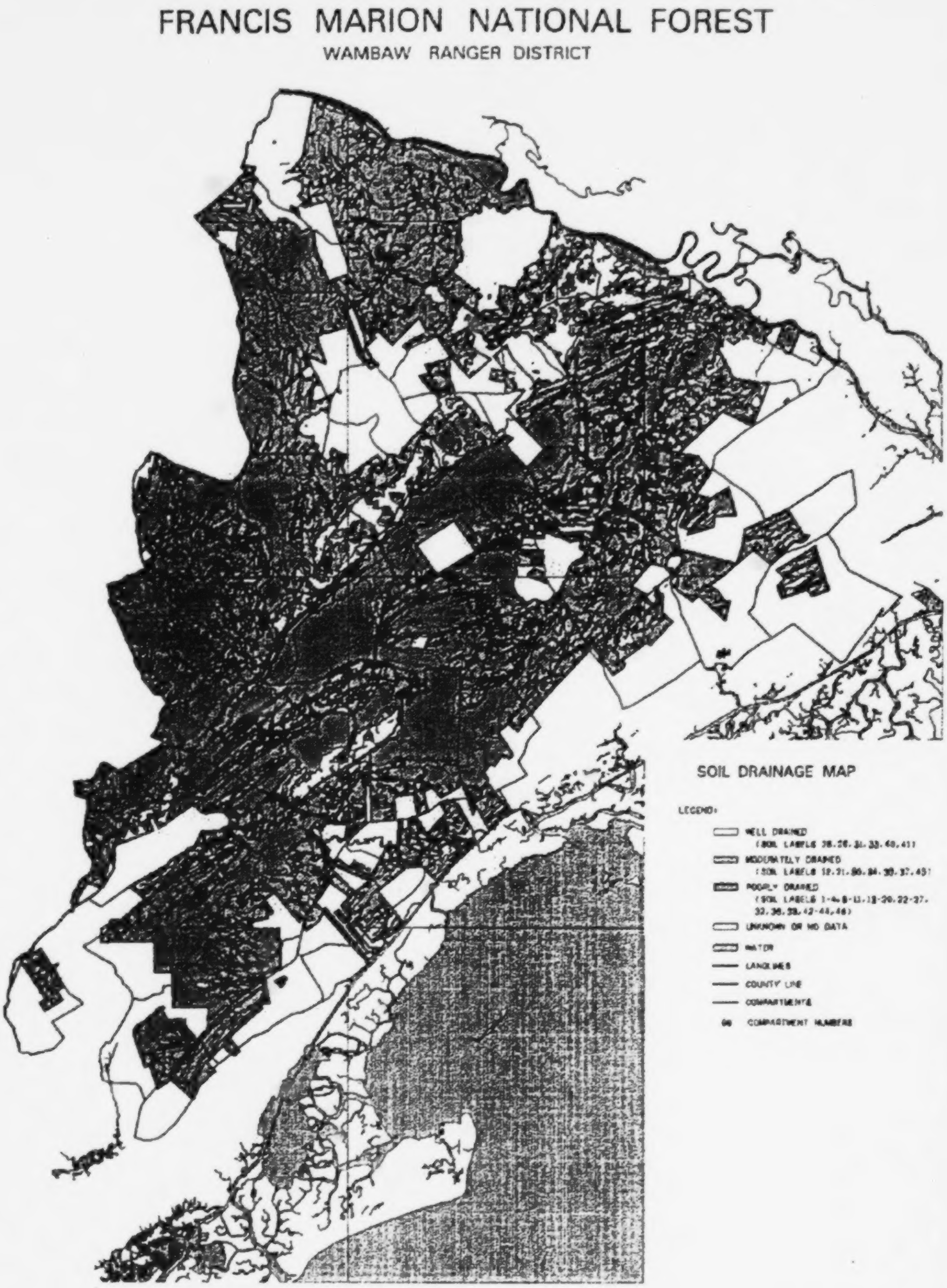

FRANCIS MARION NATIONAL FOREST
WAMBAW RANGER DISTRICT
SOIL DRAINAGE MAP
LEGEND:
WELL DRAINED
(SOIL LABELS 28.29.31.35.40.41)
MODERATELY DRAINED
(SOIL LABELS 12.21.30.34.35.37.45)
POORLY DRAINED
(SOIL LABELS 1-4.6-11.13-20.22-27.
32.36.38.42-44,46)
UNKNOWN OR NO DATA
WATER
LANDLINES
COUNTY LINE
COMPARTMENTS
COMPARTMENT NUMBERS
1 INCH = 1 MILE
N

FIGURE 4

MAP OF SOIL DRAINAGE

FRANCIS MARION NATIONAL FOREST

WAMBAW RANGER DISTRICT

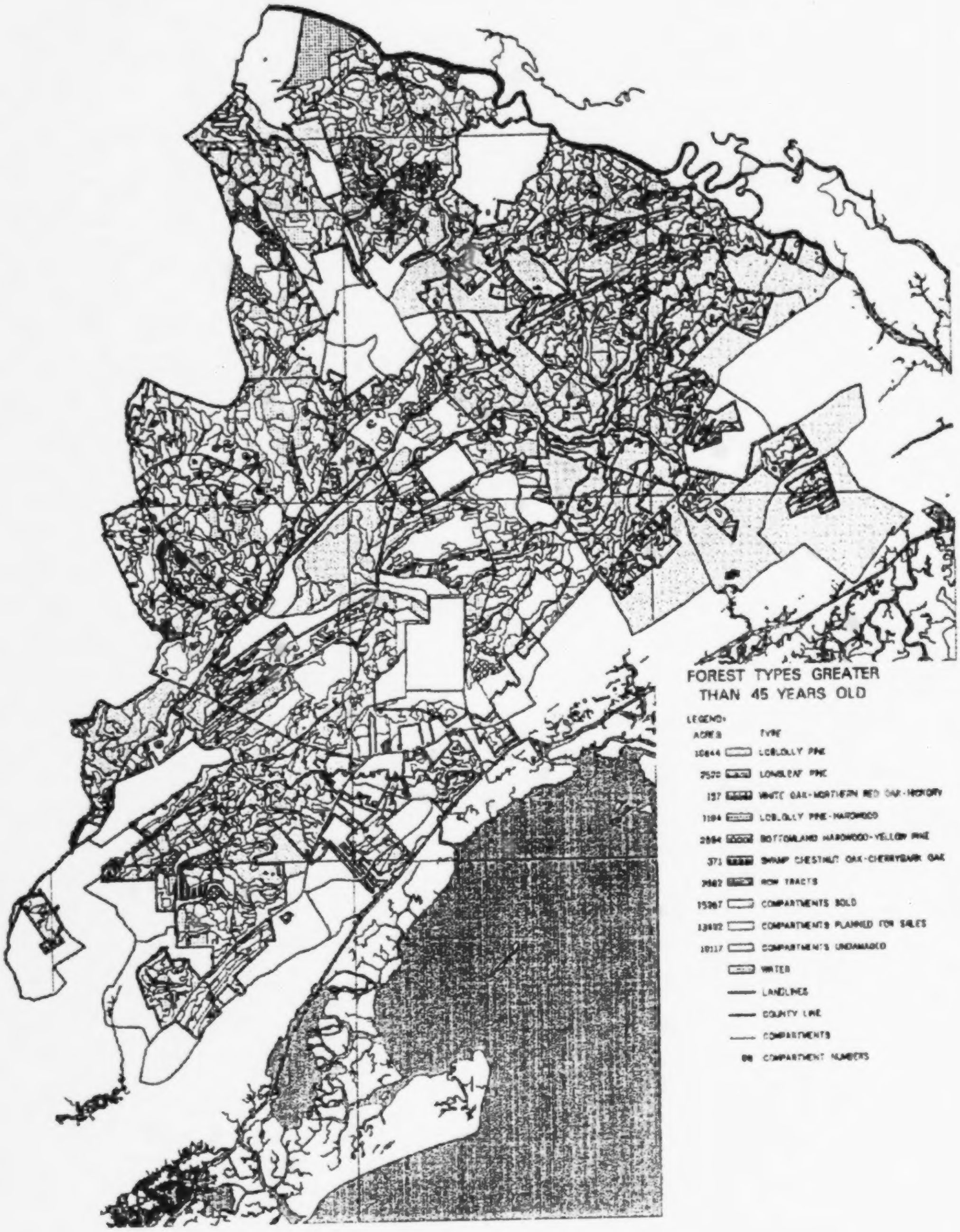
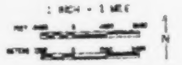

FOREST TYPES GREATER THAN 45 YEARS OLD
LEGEND:
ACRES
TYPE
10644 LOBLOLLY PINE
7520 LONGLEAF PINE
137 WHITE OAK-NORTHERN RED OAK-HICKORY
1104 LOBLOLLY PINE-HARDWOOD
2984 BOTTOMLAND HARDWOOD-YELLOW PINE
371 SWAMP CHESTNUT OAK-CHERRYBARK OAK
7982 ROW TRACTS
15267 COMPARTMENTS SOLD
13402 COMPARTMENTS PLANNED FOR SALES
10117 COMPARTMENTS UNDAMAGED
WATER
LANDLINES
COUNTY LINE
COMPARTMENTS
00 COMPARTMENT NUMBERS

FIGURE 5


1 INCH = 1 MILE
N

MAP OF RED COCKADED WOODPECKER COLONIES

index, forest type, management type, and various prescriptions. Active red-cockaded woodpecker colonies were also stored as attributes to stands. The manuscripts were prepared on mylars and pin registered to a cronoflex of the 1:24 000 7 1/2 minute base maps.

These data were digitized in a manner so that coincident lines were only entered once and copied to all layers which required that segment. This resulted in a vertically integrated data base which will not produce 'slivers' when overlays are made. The entire data base was produced in about nine months and cost about $3,500 per 7 1/2 minute quad.

Use of the GIS

The role of the GIS for the applications described in this paper was primarily to display graphically, combinations of attributes to forest stands with the roads and water 'turned on' for orientation. Forest ownership and administrative compartment boundaries became important when considering management decisions and particularly when acreage figures were needed. Text was associated with features such as rivers, county names, compartment numbers and wilderness areas for orientation.

Some of the first concerns of interdisciplinary team were to determine and map the areas that were not damaged by the hurricane. These areas would require little or no action. Figure 3 clearly shows the compartments to which this applied. Next, it was of interest to show the compartments where timber salvage rights were already sold, because little or no action had to be taken in these areas (also shown in Figure 3). The harvestable age for both longleaf and loblolly pine sawtimber was determined to be 45 years in this forest. Therefore, it was of interest to isolate those stands of pine 45 years or older (harvestable) which were in areas that were damaged and had not already been sold. These were the areas where harvest for storage would be concentrated (also shown in Figure 3). Tracts with active colonies of red-cockaded woodpeckers needed to be displayed for purposes of coordinating management activities in adjacent stands as well.

The majority of the Francis Marion National Forest is on soils which are close to the water table. Logging systems (conventional ground based or aerial) used in the forest vary, based on the relationship of soil surface and depth to water table. All of the initial harvesting was concentrated on the driest sites. The remaining opportunities for harvest required special (and expensive) removal with helicopters. Therefore, Figure 4 was produced, categorizing the soil types into 1) well drained; 2) moderately drained; 3) or poorly drained. The areas that could now be considered for harvest were those of pine over 45 years of age, that had been damaged by the hurricane, that were on soils that were well drained or moderately well drained. It was of interest to consider those sites which were of the highest quality (e.g., site index greater than 90). Figure 5 shows the tracts with red-cockaded woodpecker colonies with a 3/4 mile zone around them. Current policy restricts harvesting within this zone. Finally, manually overlaying the soils map, Figure 4 over Figure 5 permitted the team to identify stands which were candidates for harvest.

Summary

GIS expedited a spatial and visual picture for the team to identify areas where actions were to be concentrated. Stands which were candidates for harvesting were be isolated and mapped. Priority decisions were made by the team for timber sale area packaging. Acreage figures and approximate volumes were then determined.

Initial estimates of the volume of damages timber were adjusted from one billion board feet to 750 million board feet based upon the analysis done with the GIS. The GIS not only facilitated development of the strategy for recovering from Hurricane Hugo but it made it possible to share the specific planned actions with Forest Service managers, state resource management organizations and other federal agencies. While only very 'simple' GIS analyses were made (mainly displays of selected attributes to stands) the benefits were tremendous. They were made in a very timely manner, factoring in water, cultural and wildlife resource data to yield better decisions, meshing complex issues and concerns.

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GIS'90 Symposium

Vancouver, British Columbia
March 1990

Habitat Suitability Analysis and Impact Assessment with GIS-based Logistic Multiple Regression Modeling

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Abstract
Multivariate statistical techniques were applied to the development of habitat suitability models for the Mt. Graham red squirrel, an endangered species. A digital map database and a Geographic Information System (GIS) were used to support the analysis and provide inputs for logistic multiple regression models. Squirrel presence/absence is the dichotomous dependent variable whose probability the models attempt to predict and the independent variables are a set of environmental factors. Potential habitat losses resulting from development of an astronomical observatory were assessed using the environmental model and found to represent about 3% of the currently available habitat.

Introduction

Mount Graham, in the Pinaleno Mountains of Graham County, Arizona, 200 km. northeast of Tucson is the third highest mountain in the state, with a maximum elevation of 3278 m. at High Peak (Figure 1a). The Forest Service is responsible for land management of the area, as part of Coronado National Forest. In 1984, the University of Arizona's Steward Observatory concluded a nationwide search for a new observatory location, by identifying Mt. Graham as a site of outstanding quality for astronomical research (Columbus Project Science Advisory Committee, 1987), and submitted an astrophysical site and facility development proposal to Coronado National Forest. Besides its potential for astronomical research, Mt. Graham is also an exceptionally interesting mountain from an ecological standpoint. Biogeographic isolation of the Pinalenos in general and particularly of Mt. Graham, restricts gene flows of several species, giving the mountain a 'sky-island' character that facilitates the evolution of endemisms among both plants and animals. One of these is an endangered sub-species of red squirrel, *Tamiasciurus hudsonicus grahamensis*, the Mt. Graham red squirrel (U.S. Forest Service, 1986). Concern over the preservation of these ecological values led Coronado National Forest to initiate an extensive environmental impact assessment study (U.S. Forest Service, 1986). The present research was a contribution to that effort, focusing on habitat suitability analysis for the Mt. Graham red squirrel and an estimation of potential habitat losses due to implementation of the observatory project.

Red Squirrel Ecology

The Mt. Graham red squirrel study area designated by the Forest Service (U.S. Forest Service, 1988) covers approximately 6460 hectares of the upper part of the mountain, ranging in elevation from 2275 m to 3278 m. It is formed by a series of rolling areas surrounded by steep edges and narrow canyons, especially along the northern and eastern edges. Major land cover types are conifer forests, spruce-fir, mixed, and ponderosa pine, with small patches of aspen, meadows, cienegas, and rock outcrops (U.S. Forest Service, 1986). The relationships between the endangered red squirrel and its environment are primarily shaped by the need for appropriate food sources and cover conditions. The Mt. Graham red squirrel's diet is not well known, except for the importance of conifer seeds from closed cones and limited evidence indicating that at least eight species of mushrooms are also consumed (U.S. Forest Service, 1988). Seed productivity of Mt. Graham conifers was ranked by Jones (1974), with Douglas fir as the most productive species, followed by Engelmann spruce, corkbark fir, and lastly, Ponderosa pine and white pine. Engelmann spruce and corkbark fir are considered the main suppliers of food to the red squirrel (U.S. Forest Service, 1988).

Red squirrels are territorial animals, very aggressive toward both conspecifics and other species of tree squirrels (Flyger and Gates, 1982). Size estimates of the average activity area vary between 0.5 and 1.0 hectares and territoriality is expressed by central place foraging behavior, meaning that harvested cones are carried to a central place of the territory or activity area, where they are piled up or buried for winter and next year's supply (U.S. Forest Service, 1988). These piles, or middens, consist not only of cones but also scales, cone cores and sometimes needles (Hoffmeister, 1986). It is critical that cones remain humid, otherwise they crack open and the seeds become susceptible to theft by other animals. Therefore, red squirrels look for damp, shaded spots (Rothwell, 1979), requirements that make obvious the role of tree cover and topography in habitat selection.

The Digital Database

Given the explicit spatial nature of the habitat analysis and impact assessment problems, it was decided to develop a digital cartographic database capable of supporting analysis and decision making, and based on previously collected information. Elevation (Figure 1a) and road network (Figure 1b), as well as project location data (Figure 2f), were obtained from USGS 7 1/2' quadrangles, vegetation data (Figures 1e and 2c-e) from a Forest Service stands map, and squirrel activity data (Figure 1d) from a Forest Service survey map. Digitization was performed with the CADGRID software package (Itami, 1988). All maps were referenced to the UTM rectangular coordinate system and were available at a scale of 1:24 000 (Pereira, 1989).

The three base maps mentioned above were transfered to Map Analysis Package (MAP) (Tomlin, 1986), the PC-based raster geographic information system, where a set of nine other layers was developed using various GIS operations. Slope and aspect maps (Figures 1b and 1c) were derived using the 'differentiate' and 'orient' operations, respectively. Both maps contain continuous interval data, with slope measured in % values and aspect in degrees azimuth. Since aspect refers to circular data, this variable was transformed to a format suitable for conventional statistical analysis by decomposing the information for each cell into a north-south and an east-west component (Pereira, 1989). The vegetation-related derived maps, vegetation types (Figure 2c), canopy closure (Figure 1e), food productivity (Figure 2d) and diameter at breast height (dbh) (Figure 2e) were obtained using the 'recode' operation on the original Forest Service stands map. The first of these maps contains nominal information, while the others use ordinal scales. The roads map (Figure 2a) was combined with the canopy closure map to produce a distance to openings map (Figure 2b), as a layer of continuous interval data. The squirrel activity map is a binary presence/absence map, and the project location (Figure 2f) map simply displays the location of project phases 1 and 2.

A cell size of 0.5 ha., corresponding to a length of 70.7 m. on a side was selected, resulting in a minimal bounding rectangle of 164 rows by 193 columns, for a total of 31 652 grid cells. Of these, 12 920 are contained within the study area and 18 732 outside of it. Three reasons dictated the choice of a cell size of 0.5 ha. First, it corresponds approximately to the smaller sizes of the range of red squirrel activity areas, which is the basic unit of analysis of the study. Second, mapping accuracy in the original map of activity areas provided by the Forest Service, made it

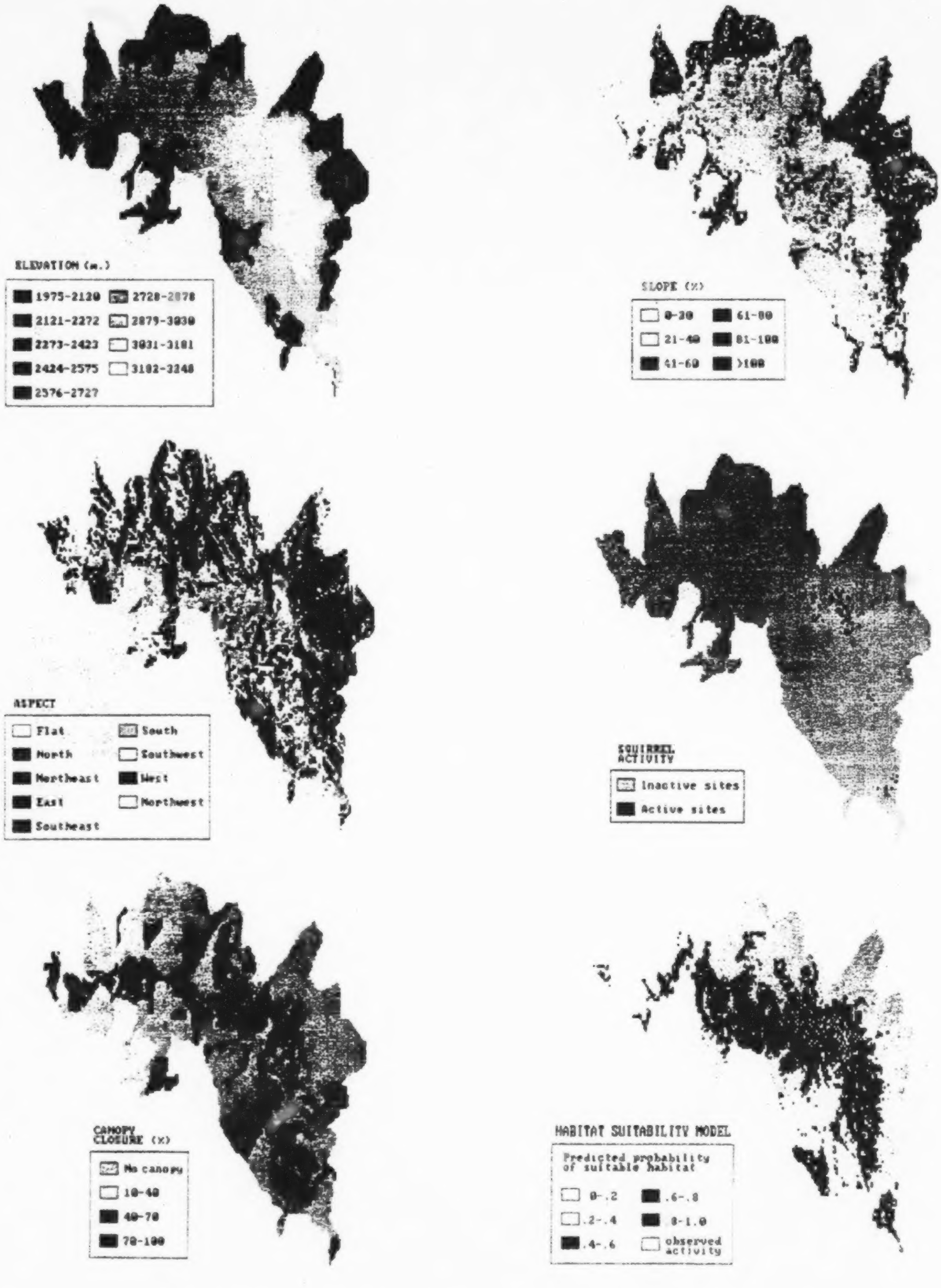
ELEVATION (m.)
1975-2120
2121-2272
2273-2423
2424-2575
2576-2727
2728-2878
2879-3030
3031-3181
3182-3248
SLOPE (%)
0-20
21-40
41-60
61-80
81-100
>100
ASPECT
Flat
North
Northeast
East
Southeast
South
Southwest
West
Northwest
SQUIRREL ACTIVITY
Inactive sites
Active sites
CANOPY CLOSURE (%)
No canopy
10-40
40-70
70-100
HABITAT SUITABILITY MODEL
Predicted probability of suitable habitat
0-.2
.2-.4
.4-.6
.6-.8
.8-1.0
observed activity

Figure 1. Maps corresponding to variables selected through stepwise regression, observed squirrel activity, and resulting habitat suitability model.

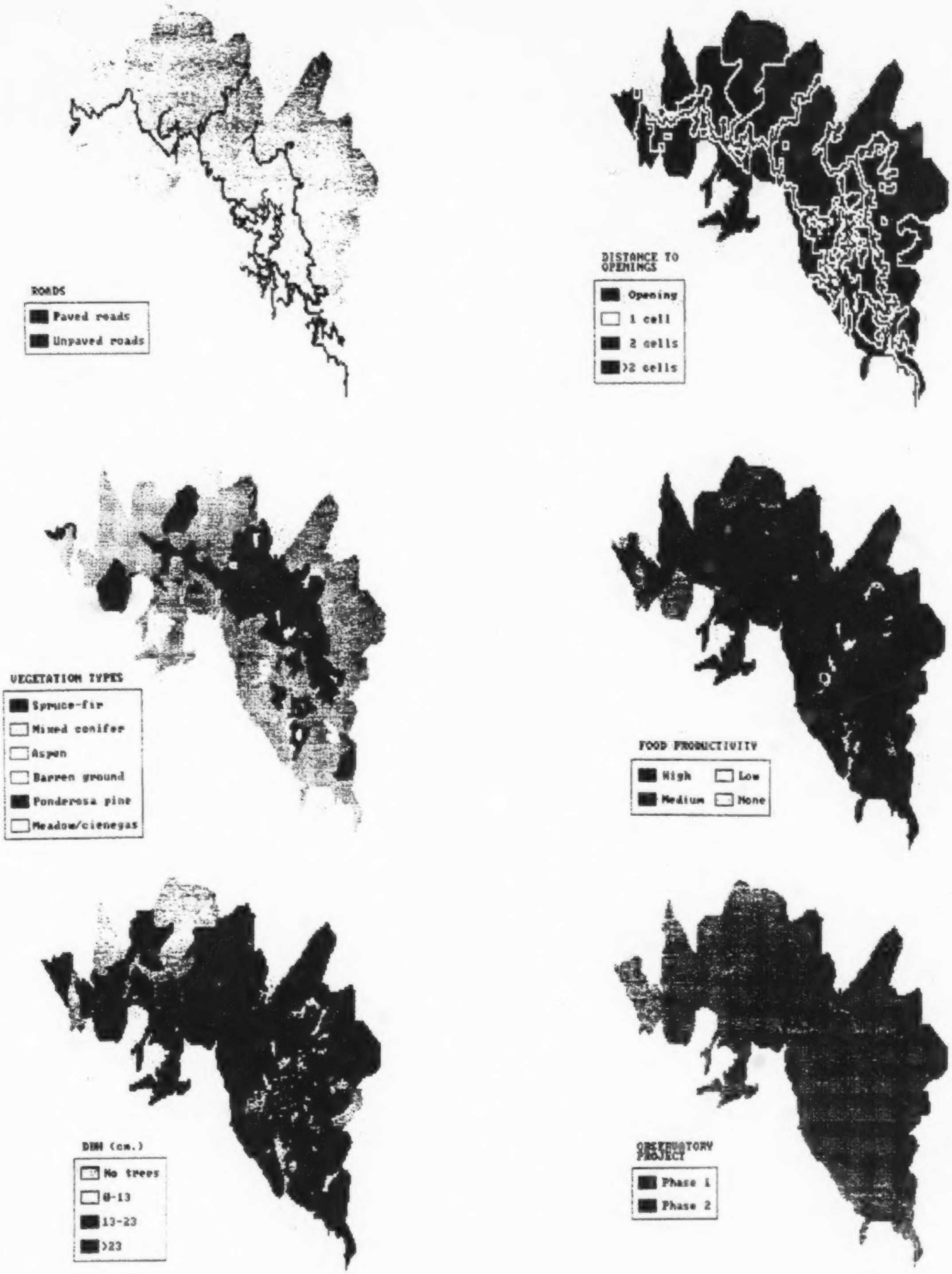
ROADS
Paved roads
Unpaved roads
DISTANCE TO OPENINGS
Opening
1 cell
2 cells
>2 cells
VEGETATION TYPES
Spruce-fir
Mixed conifer
Aspen
Barren ground
Ponderosa pine
Meadow/cienegas
FOOD PRODUCTIVITY
High
Low
Medium
None
DBH (cm.)
No trees
0-13
13-23
>23
OBSERVATORY PROJECT
Phase 1
Phase 2

Figure 2. Database maps of unselected model variables and project location.

unadvisable to use a smaller cell size. Third, there were software limitations imposed by MAP, which cannot handle arrays larger than 32 767 grid cells, very close to the total actually used for the Mt. Graham database (Pereira, 1989).

Habitat Evaluation Procedures and Study Design

Structured frameworks for habitat evaluation were first developed in the mid-1970's by the Forest Service and the Fish and Wildlife Service. The latter's Habitat Evaluation Procedures/Habitat Suitability Indices (HEP/HSI) (U.S. Fish and Wildlife Service, 1980, 1981) are especially appropriate for what Thomas (1982) calls 'featured species management', the production or preservation of selected species in desired numbers, at specified places. HEP/HSI are particularly suitable when there is a single species of concern, as was the case with the Mt. Graham red squirrel.

This study's objective was, therefore, to predict the probability of red squirrel presence or absence from each study area grid cell, contingent on a series of environmental and descriptor variables. Given the binary nature of squirrel activity data, logistic regression or discriminant analysis are the available modeling techniques but, considering that some of the independent variables, e.g., food productivity, canopy closure, dbh, are qualitative, logistic regression is more appropriate (Press and Wilson, 1978).

The sample data were taken from the digital database maps. Henceforth, database grid cells where squirrel activity was present will be refered to as 'sites' or 'active cells', while those from where squirrels were absent will be called 'non-sites' or 'inactive' cells. The sample data can be conceptualized as a two-way table or matrix, with observations (grid cells) as rows and cell descriptors as columns. These descriptors include environmental variables of the database overlays and an indication of presence,1, or absence,0, of squirrel activity.

Two major considerations affected sampling design. Since non-site locations correspond to the vast majority of the study area, larger variation is expected in environmental attributes for this group. A ratio of non-sites to sites larger than one is therefore desirable (Kvamme, 1985). There are 212 active cells in the database and therefore, the sample should include a value larger than that for inactive cells. On the other hand, spatial autocorrelation structure in the independent variables had to be considered, in order to assess how to minimize it through systematic sampling (Haining, 1980). Moran's I coefficient (Cliff and Ord, 1981; Upton and Fingleton, 1985), as implemented in the autocorr procedure of the IDRISI GIS package (Eastman, 1987) showed that for a first order lag, spatial autocorrelation values for each independent variable were close to unity, but when a seventh order lag was reached, Moran's I had dropped to values between 0.34 for the elevation overlay, down to 0.16 for the slope layer. A systematic sampling scheme was then followed, where each seventh cell in the database was selected, in both row and column directions. This yielded a sample of 259 non-site cells.

Environmental Model

Logistic multiple regression models were developed, using environmental factors as explanatory variables. The categorical nature of the vegetation descriptors (food productivity, canopy closure, and dbh) requires their recoding as dummy variables prior to inclusion in any regression model. Each one of these variables has four categories and must then be recoded to three dichotomous dummy variables (Wrigley, 1985), for a total of 9 new variables.

The full environmental model includes these nine variables plus elevation, slope, aspect N/S, aspect E/W, and distance to clearings, for a total of 14 variables. Concern over model stability, which requires a high ratio of number of observations to number of variables (Kleinbaum et al, 1988) led to the use of three random sub-samples of the original data matrix. Out of each sub-sample, 75% of the data were used for training purposes, and 25% left out for independent

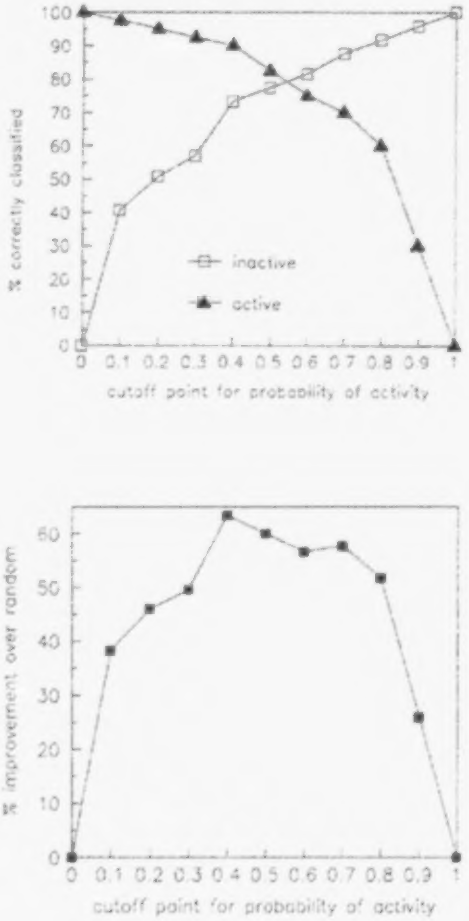

Figure 3. a) Classification error rates and b) Model predictive improvement over chance at various classification cutoff levels.

model validation. Each sub-sample was subjected to stepwise regression, in order to simplify the full specification and generate more parsimonious models. Both backward ('p-to-leave' = 0.00) and forward ('p-to-leave' = 1.00) procedures were applied, resulting in a total of 6 environmental models.

Classification error rates measure how well a model generalizes to independent data and these rules were applied to the part of the sub- samples not used for training purposes. Three of the models converged on formulations including elevation, slope, aspect E/W, and canopy closure as the statistically significant variables. One of these models, corresponding to the backward elimination procedure applied to sub-sample 1, shows the best classification error rates. At an optimum probability cutoff level of 0.4, it correctly identifies 90% of the squirrel activity, while covering only 27% of the study area (Figure 3a and 3b), which represents a 63% improvement of predictive power over chance. It was selected as the best environmental model and is represented by the equation:

$$
\begin{aligned}
(1)\ Y = \ & 0.002 \times \text{elevation}\ 0.228 \times \text{slope} + \\
& 0.685 \times \text{canopy1} + 0.443 \times \text{canopy2} + \\
& 0.481 \times \text{canopy3} + 0.009\ \text{aspectE/W}
\end{aligned}
$$

where Y is the probability of success, i.e., the probability of squirrel presence at a given cell. A habitat suitability map for the red squirrel was created by applying equation (1) to the map overlays representing model variables. The result is a map of continuous probability values, that was discretized into five categories and overlaid with the activity areas map to facilitate comparisons between observed spatial patterns of squirrel activity and model predicted suitability (Figure 1f). The strong predictive power of the model, suggested by the classification error rates results, is clearly shown in this map, as the agreement between squirrel presence and predicted high suitability is especially obvious at the two areas of more concentrated activity.

Spatial Impact Assessment

The main goal of the study is to assess the amount and quality of red squirrel habitat that will be lost due to development of the astronomical observatory, with the underlying assumption that habitat losses can be used as a proxy measure for impact on long-term survival of the population. Squirrel habitat equivalents (U.S. Forest Service, 1988) is the concept that translates measurements of affected area into population impacts. Squirrel habitat equivalents equal the number of red squirrels that could be supported by a given habitat acreage, and are calculated by overlaying the project location areas (Figure 2f) on the environmental habitat suitability map (Figure 1f). This determines the number of cells, or acreage lost in each suitability class. Density of squirrel activity areas by suitability class was calculated by overlaying the squirrel activity map (Figure 1d) on the habitat suitability map and dividing the number of activity areas in each suitability class by the number of cells in that class. The number of squirrel habitat equivalents lost in each suitability class is given by the product of density of activity times acreage lost. Summation over all suitability classes determines the overall losses.

Squirrel habitat equivalents lost to development were calculated using the data in Table 1. Phase 1 of the observatory project will cause the most impact, leading to the loss of 3.5 units while phase 2 is estimated to impact 3.2 habitat equivalents. A fully developed observatory would have an impact of 6.7 squirrel habitat equivalents, or approximately 3% of the 212 activity areas identified in the 1986-87 census and taken as a base population level for this study. These impact magnitude estimates assume that all habitat will be lost in a 70.7 m. wide corridor, which is the best approximation to the true impact, permitted by the grid-cell resolution. This value may overestimate the direct spatial impact of developing the observatory but it should be a better estimate of overall impact, which includes clearcutting, paving, construction, and other negative effects of human presence, such as noise, smells, movement, etc.

Table 1. Spatial impact assessment of projected astronomical observatory.

Suitability Class	Activity Density	Number of cells Lost		Number of Habitat Equivalents Lost	
		Phase 1	Phase 2	Phase 1	Phase 2
0-0.1	0	0	0	0	0
0.1-0.2	0.004	0	0	0	0
0.2-0.3	0.005	0	0	0	0
0.3-0.4	0.009	0	0	0	0
0.4-0.5	0.017	2	1	0.034	0.017
0.5-0.6	0.025	8	1	0.200	0.025
0.6-0.7	0.019	19	1	0.361	0.019
0.7-0.8	0.028	11	4	0.308	0.028
0.8-0.9	0.089	12	5	1.068	0.445
0.9-1.0	0.150	10	18	1.500	2.700
Total	-	62	31	3.471	3.234

It is worth recalling that habitat area lost is a proxy measure of the project impact on population size. The Mt. Graham red squirrel is in danger of extinction and preservation of its habitat is a necessary, if not sufficient, condition for long-term survival. However, even though impact magnitude can be estimated, it is much harder to determine what will be the importance of a given impact, that is, how will it influence the attainment of the desired goal of maintaining a viable red squirrel population. Continued monitoring of population dynamics and habitat status will be needed, to make sure that the various uses sought for the mountain can be conciliated and are not ultimately incompatible.

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Managing Resource Conflict

Session A7
Decision Support Systems

A Water Information System Case Study

Cartographic Modelling of Riparian Buffers

Three-dimensional Computer Mapping

Water Resource Applications of GIS in the State of Idaho

GIS'90 Symposium

Vancouver, British Columbia
March 1990

A Water Information System Case Study

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Abstract

Over the past few years the Institute of Hydrology has amassed a large and rapidly growing number of national spatial and time-series data sets. A variety of techniques for handling these data have been, and continue to be, developed. To disseminate the results of this work, and to create the base from which future research can proceed, it has been decided to bring together these elements to produce a unified system. The principle novel feature of this Water Information System (WIS) is the ability to exploit time-series and spatial data together.

This paper describes the background to the development of WIS, and the design philosophy behind it. The route which we are taking to implement WIS as a working system is also described.

In WIS, particular emphasis is placed on applications. Another key aspect is the way the user communicates with the system in a natural way, through digital maps and an extensive command language. An important role of the system is seen to be the effective presentation of data. This is necessary both for operational work and to meet the demands of national and European legislation relating to the UK water industry.

1. Introduction

The first release of a system, for exploiting scientific and technical water data, is nearing completion at the Institute of Hydrology (IH). There are two driving forces behind this project; one is the Institute's need for an advanced system to further its own research programme, the other is the need of the recently reorganised UK water industry to update its systems.

This paper describes the background, design philosophy and implementation of the system.

1.1. IH Requirements

IH research addresses a broad range of problems concerned with water, and many of these problems can be approached by considering the 'geography' (in its broadest sense) and man's 'use' of a region. As an example, the Flood Studies Report (NERC, 1975) and the Low Flows Study (IH, 1980) provide means of estimating river flow statistics at ungauged sites. Both methods relate flows to quantities describing the site's catchment, readily available on maps. To automate the derivation of such 'catchment characteristics' many map data have been digitised; other data have been captured directly in digital form, for example from remotely-sensed images. Table 1 illustrates some of the spatial data held at IH.

Possibly the most important of these data sets for IH research, in the near future, is the set of contours and related data. From this information, IH has derived a fifty by fifty metre grid of elevations, a digital terrain model (DTM), of Northern Ireland (Morris et al, 1988); complete coverage of Great Britain will follow. Using the DTM it is possible to trace a flow path from any point on the land surface to the sea. Reversing the process allows the catchment watersheds to be derived (Figure 1). The reliable automation of this process is the key to automating many hydrological design procedures. Digital terrain data also make feasible new approaches to hydrological problems since, for the first time, digital information, in a form amenable to analysis, is available on the extent and shape of a catchment. However, because the data volumes are very large, the new techniques are only practicable if the data are held in a highly ordered manner.

So far, as each of these data sets has arrived in the hands of different researchers, new data structures have been designed and different methods of analysis devised. The data have been spread out over a number of systems, such as the relational database, Oracle (Oracle, 1988), and an IH hierarchical database, Cache-Cache (Sekulin, 1986). This situation has inhibited IH's ability to exploit the data sets, and to explore possible relationships between them. Hydrology is not only about spatial variations, but also about temporal variations in the water cycle. The problems of studying relationships in the latter are just as great as those in the former. The difficulties are even greater when trying to examine problems in both space and time, say in long-term regional and national pollution studies or in analysing the effects of a passing storm. Looking again at the flow statistics example, better estimates can be gained by using flow data from a nearby river gauging station, as long as its catchment has similar characteristics to the one being studied.

There is a strong need to tackle these problems, and the proposed solution is to assemble all types of spatial and temporal data into a single system.

1.2. Water Industry Requirement

The recent sale of the English and Welsh water utilities to the private sector was accompanied by the creation of the National Rivers Authority (NRA). Among other things, the NRA is responsible for policing the activities of the private water companies, and for making data available to the public.

Data set	Coverage
River & lake shores from 1:250 000 sclae maps	England, Scotland & Wales
River & lake shores from 1:50 000 scale maps Scotland	Northern Ireland, England, Wales & 30%
Long-term annual average rainfall & other meteorological statistice	UK
Rainfall radar	2 sites in England
Soil maps at 1:250 000	England, Scotland & Wales
Contours, coastling & spot hieghts from 1:50 000 scale maps	Northern Ireland, Wales, & 50% England
Point locations of many measurement sites, artificial influences on flow, & other features of interest	
Remotely-sensed data (Thematic Mapper)	UK

Table 1. Examples of spatial data held at IH.

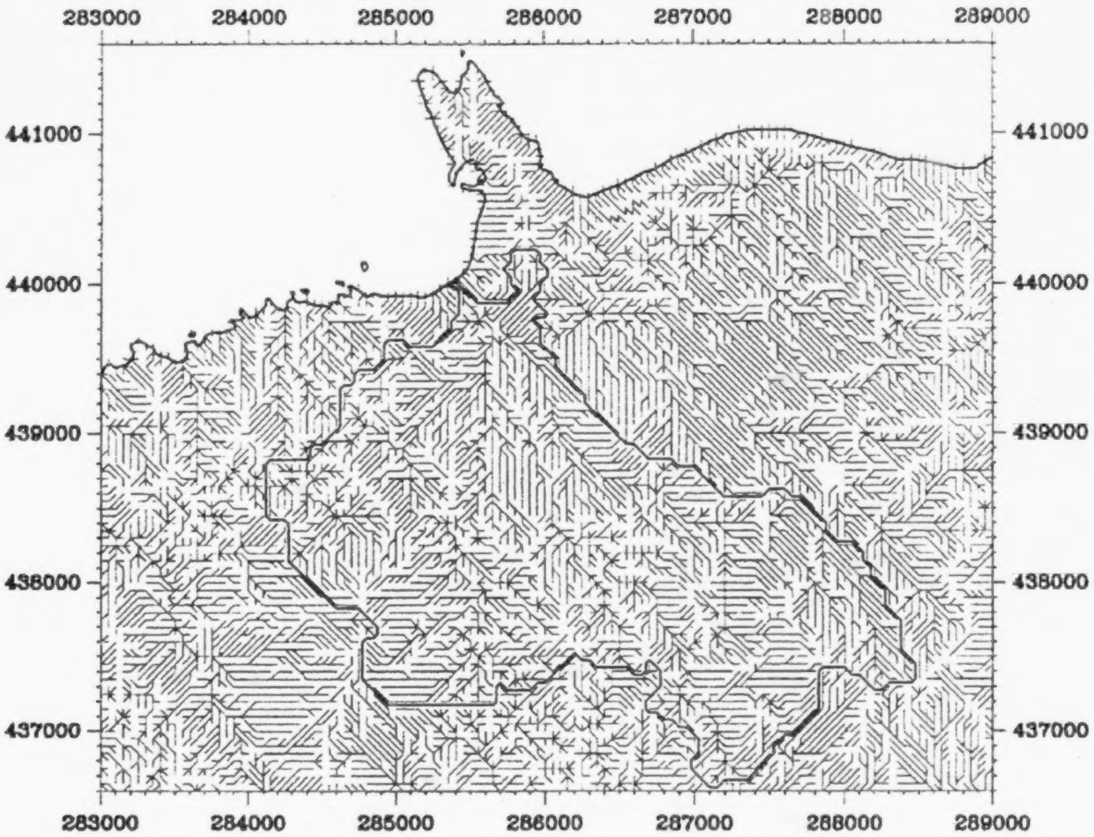

Figure 1. Catchment boundary and flow paths derived from a terrain model.

Much of the water industry currently uses the Water Archive System (Rodda et al, 1978). This system is quite old and slow, not interactive, and provides little in the way of graphics. Also, only very limited types of spatial data can be stored in it. A replacement system is needed which will be better able to store and use a very rapidly growing volume of information.

The water industry has a requirement for a system similar to that needed by IH, though there is much more emphasis on operational rather the research applications. Because of the operational considerations and the possibility of public access to the system, the ease with which it can be used is more important. Ideally, where appropriate, the user should communicate with the system via maps and pictures, rather than needing to know codes and reference numbers.

Table 2 lists just a few water industry applications which could be aided by an integrated system. One example, that illustrates how important it is to bring together spatial and time-series data, is the drawing of river quality survey maps. These maps show a river network with the width of the river related to flow, and the colour to the degree of pollution. What is required is a system which will climb the river from its mouth and, as it passes flow and water quality measurement sites, alter the graphical representation according to the measurements from each site.

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river flow estimation
production of river quality maps
determination of consent conditions for discharges & abstractions
asset management
pollution control
assessment of the vulnerability of groundwater to pollution
fisheries - production of fish maps
provision of public registers of water quality samples
sea defences
erosion potential
drought management
recreation & amenity

Table 2. Examples of water industry applications

1.3. Project and System Objectives

From this background, the overall requirement that has emerged is for a system for storing, manipulating, displaying and analysing spatial and time-series data. Important functions that the system should provide include the ability to:

Store time-series data - two million water quality samples are taken each year. These will have to be explicitly associated with their sampling points. Rapid and flexible means of access via maps to the raw data is needed.

Store raster (gridded) data - very large volumes of raster data are to be stored; the DTM, for instance, will have over one hundred million points. These raster data require rapid analysis and combination with other data, both raster and vector.

Store vector data - it is not enough to record simply the location of 'features' of interest. The relationships between features need to be stored so that, for example, a river network can be climbed from the mouth to all sources.

Support applications - the ability to introduce completely new analyses efficiently and easily into the system is essential. As far as possible, the system should be flexible and general in order to cope with the unforeseen.

Support concurrent update - the system should provide for a number of users to update the database, particularly the time-series data, at any one time.

Be portable - the system should not be tied strongly to particular hardware or operating systems.
Though very comprehensive, flexible and elegant systems are available, we were not able to find a system to meet these demanding needs. Therefore, it was decided to develop a new system, around proven elements.

2. System Development

IH exists to do hydrological research, not to develop major software products, and external funding was therefore essential. To attract the necessary money, a small demonstration system was set up to illustrate some of the basic concepts, and an overall requirements specification was written. With these to hand, various parties, both within the Natural Environment Research Council (NERC, of which IH is a component body) and in the UK water industry were visited; many showed a strong interest.

With the increasing interest of the water industry came also the attention of the largest UK computer manufacturer, ICL, whose equipment is widely used in the water industry. A joint project was established to produce a complete system of software, hardware and support services. IH provides design and programming effort, ICL provides hardware (Sun workstations), support finance, and marketing and project management.

This process took about fifteen months, and resulted in programming work starting in February 1989. The system is now undergoing trials at a regional office of the NRA. It is intended to release a full version of the Water Information System (WIS), as it has become known, in the autumn of 1990.

3. Design Constraints

As with any such development, there are a great many constraints. The overriding ones are those of time and manpower which, in general, reduce to one of cost. To minimise immediate and future costs development is being based on existing software. Where possible, this software complies with international standards; the resulting system is then more likely to survive changes of computer hardware or operating system. This is particularly important as a range of computer architectures is to be catered for, from microcomputers to mainframes.

As the basis for development, it was resolved to use a relational database having the standard Structured Query Language, SQL (ISO, 1987). IH and the rest of NERC are already using Oracle (1988), while ICL's 'strategic' product is Ingres (1988). It was therefore decided to develop both Oracle and Ingres versions of WIS; it is hoped that as both products comply with the SQL standard, this will not be an onerous commitment.

Multi-user access and a high level of system reliability, in recovery and security, are important objectives. A long-term goal is that WIS should also be able to work in distributed mode. By using a commercial database management system of high quality these objectives can be achieved with minimal development effort and cost.

A proportion of users wish to write their own applications and incorporate them within the system. The most widely used scientific language within the water industry is Fortran-77 (ANSI, 1978) and this has been adopted for use throughout the system. GKS (ISO, 1985) has been chosen as the graphics library, because software complying with this standard is available which is, in turn, compatible with the Fortran compilers necessary to access Oracle and Ingres on the desired range of hardware.

4. Applications

After logging on to WIS, the user is presented with a list of applications. The current range includes: general mapping, low flow estimation, catchment characteristics derivation, Control of Pollution Act (II), a dictionary editor, bulk input and output, River Quality Survey, and a simple time-series editor.

Choosing one of these gives the user access to a set of commands. Those commands required to satisfy the mapping application are summarised in Table 3. (The syntax of these commands follows that of SQL.) The initial list of applications that appears will depend upon the permissions granted to the user.

There are two main reasons for grouping commands in applications. Firstly, some users find it convenient to have applications directed at specific tasks, rather than have a

CHANGE UNDO; CHANGE <COPY/MOVE/RESIZE/ROTATE/COLOUR> OID=oid,pid; CHANGE <COPY/MOVE/RESIZE/ROTATE> <TXY=ty,ty,b/SXY=sx,sy/UXY=ux,uy>; CHANGE MOVE <TVECTOR=dtx,dty/SVECTOR=dsx,dsy/ UVECTOR=dux,duy>; CHANGE ROTATE <THETA=theta/FIX=<BL/BR/TL/TR/CE>>; CHANGE <PRIORITY OID=oid/COLOUR CID=col> CHANGE PRIORITY DIRECTION=<FRONT/BACK/ BACKWARDS/FORWARDS>;	Alters the content of the map by modifying any previously displayed object. These changes may effect the display of a single object (e.g. MOVE, RESIZE, ROTATE) or many (e.g PRIORITY).
DIDLIST ADD ATCODE=atcode; DIDLIST DELETE ATCODE=atcode; DIDLIST CLEAR; DIDLIST MEMBERS; DIDLIST SAVE IDFILE=filename; DIDLIST LOAD IDFILE=filename;	Used to set up a list of dictionary identifiers in memory. Dictionary ids are unique codes that correspond to individual attributes, thus access to the did list is through attribute codes. The did list is useful if there are several operations that need to be done on a set of attributes.
DRAW <LINE/CIRCLE/BOX/POINT/POLYGON> <TXY=tx,ty,b/SXY=sx,sy/UXY=ux,uy>; DRAW <LOCATOR/GRID MESH=msize>; DRAW FEATURE TYPE=ftype; DRAW BORDER_OBJECT BOID=boid;	Draws an object onto the screen. The object may be a simple primitive drawn by repeated issues of the command, or may be a set of primitives taken from the database, or may be a complex border object with few variable dimensions.
ERASE <ALL/OID=oid>;	Removes one or all objects from the map.
FIDLIST <ADD/DELETE> OID=segid,fid; FIDLIST <ADD/DELETE> FTYPE=ftype FNAME=fname; FIDLIST <ADD/DELETE> UCODE=ucode; FIDLIST <CLEAR/MEMBERS>; FIDLIST <SAVE/LOAD> IDFILE=filename;	Used to set up a list of feature identifiers in memory. The fid list is added to by picking features off the screen or typing in feature names or user codes. The fid list is used for doing several operations on a specific set of features.
FILE <SAVE/LOAD/PLOT> <options>; FILE <SAVE/LOAD> LOG_FILE=<OPEN/CLOSE>; FILE <SAVE/LOAD> LOG_IO=<ON/OFF>; FILE SAVE <OID=oid,pid/LOCATOR>; FILE <SAVE/LOAD> <LAYOUT=PAPER/BORDER>; FILE <SAVE/LOAD> STATUS=statname; FILE <SAVE/LOAD/PLOT> ALL;	Controls all map oriented input/output. The three driving keywords allow the saving of info, the loading of previously saved info, and the plotting of displayed data on a paper plotter. The data may be stored in the following, depending on the data being stored: a log file - ASCII 80 char command list data file; a metafile - graphic info ASCII 80 char data file; a database table.
IDENTIFY FROM_SCREEN OID=oid,pid; IDENTIFY FROM_DBASE <FNAME=FNAME> <UCODE=ucode> <TYPE=ftype>; IDENTIFY FROM_DBASE IDACTION=<START/NEXT/EXIT>; IDENTIFY FROM_DBASE IDCENTRE=<MAIN/SPLIT/OFF>; IDENTIFY FROM_DBASE <IDDRAW/IDBOX>=onoff;	Used to link between the screen display and the database name. Can work in both directions. Either a plotted object can be picked from the screen and its name and type reported, or a feature can be plotted from the database having been identified by name or type.
SCREEN <ZOOM=IN/OUT/FULL>; SCREEN <ZOOM=BOX/PAN=CENTRE> <TXY=tx,ty,b/...>; SCREEN SPLIT=<VERTICAL/HORIZONTAL> SXY=sx,sy; SCREEN <SPLIT=BOX SXY=sx,sy/SPLIT=OFF/SXY=sx,sy>; SCREEN PAN=<UP/DOWN/LEFT/RIGHT>;	Alters the display of the map on the screen. Does not alter the contents of the map.
SPECIFY SELECT_AREA <TXY=tx,ty,b/...>; SPECIFY SELECT_AREA EDGES=udx,udy; SPECIFY LAYOUT PAPER_SIZE=<A0/A1/A2/etc>; SPECIFY LAYOUT PAPER_EDGES=px,py; SPECIFY LAYOUT BORDER_POSITION=bx,by; SPECIFY LAYOUT <LMARGIN/RMARGIN/...>=mm; SPECIFY LAYOUT <FRAME_XEDGE=xm/FRAME_YEDGE=ym>; SPECIFY LAYOUT FORMAT=<PORTRAIT/LANDSCAPE>;	Allows the user to alter the areas defined during mapping. The three areas are: the SELECT AREA in which features may be selected from the database; the BORDER AREA into which the mapping module can draw objects; the PAPER AREA on which the plot will be done.
STATUS DRAWING <LINE_TYPE/POINT_TYPE/ POLYGON_EDGE_TYPE>=lid; STATUS DRAWING <LINE_THICKNESS=lid/POINT_SIZE=ps>; STATUS DRAWING <LINE_COLOUR/POINT_COLOUR/POLYGON _EDGE_COLOUR/POLYGON_FILL_COLOUR>=col; STATUS DRAWING POLYGON_EDGE_THICKNESS=lid; STATUS DRAWING POLYGON_FILL_PATTERN=pat; STATUS DRAWING <TEXT_FONT=font/TEXT_SIZE=tsize>; STATUS DEFAULT AUTOGRID=<ON/OFF>; STATUS DEFAULT AUTOGRID_SIZE=asize; STATUS DEFAULT AUTOGRID_TYPE=<SCREEN/TABLET/USER>; STATUS DEFAULT AUTOGRID_DISPLAY=<ON/OFF>; STATUS DEFAULT CONFIRM=<YES/NO>; STATUS DEFAULT <ZOOM_FACT/PAN_FACT>=zfact; STATUS DEFAULT FULL_DISPLAY=<SHEET/BORDER/SELECT>; STATUS DEFAULT LOCATOR=locname; STATUS DEFAULT <METAFILE=mfile/LOGFILE=lfile>; STATUS DEFAULT PICK_SIZE=psize; STATUS DEFAULT CURSOR=<ARROW/CROSS/CROSSHAIR>; STATUS DEFAULT <STATUS=statname/LAYOUT=layname>;	Used to alter many of the values that control the other mapping commands. There are two main sections: the DRAWING keyword controls the way the objects mapped by the DRAW command are displayed; the DEFAULT keyword is used to define many of the variables that all other commands use for their defaults.

Table 3. The mapping commands

single totally general system. This is particularly true of infrequent users. Secondly, it enables certain commands to be reserved to named users. This is valuable where a particular team has responsibility for, say, the update of the database.
Users who prefer the general system approach are still catered for, as a 'super application' can be created which has access to all commands.

The scheme described exploits the fact that there are large areas of overlap between applications, for example, many require mapping facilities. Also, many applications are specific examples of a general case, particularly graphs, reports and maps. By providing a set of tools, repeated provision of the common areas is avoided. Users can then define their own applications without necessarily needing a system change.

5. Data Structures

The ability to exploit spatial and time-series data is strongly dependent on the way in which they are stored.

The world as seen by WIS is made up of 'features', which are generally physical objects having position and shape. The features can be described and those descriptions may vary in time. Features may relate spatially and administratively to other features, for example, a set of sampling points within a sewage works.

The minimum information needed to record a feature's existence are its type, class and a unique system-supplied identifier. A feature type is a broad physical grouping of features, such as river stretches or reservoirs. A feature class identifies the spatial nature of a feature. Examples of feature classes are lines, points, abstract things, or complex objects comprising many other features.

At its simplest level, the WIS data model is that shown in Figure 2. It is most important to note that none of the three types of data is mandatory.

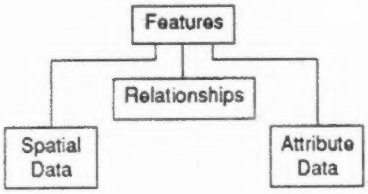

Figure 2. Overall data structure

Relationships allow for the building up of complex features from a set of simpler ones. Also, relationships between features which are complete in themselves can be stored, tying a water quality sampling point to a river stretch.

The WIS data model handles the spatial data types illustrated in Figure 6. Spatial data are split into two broad groups: vector and gridded (or raster). Vector data cover points, lines, networks, polygons and areas. A polygon describes a closed shape such as the outer edge of a wood. An area is the space described by one outer polygon and any number of inner ones which might, say, show clearings in a wood. Polygons are built up from lines, areas from polygons.

Three categories of gridded data are catered for. A grid image is typically a photograph or a remotely-sensed image. It has some spatial reference, say the grid reference of a photographed gauging station, but does not have its entire area explicitly referenced to the ground. A continuous grid is derived from a continuously varying surface, such as terrain. A discrete (or plateau) grid describes a surface with a limited set of possible values, for example, a soil map.

Features may also have attributes describing them, and these are generally part of a time-series. Thus, the width of a weir may be stored for a river gauging station. More typical perhaps are measurements taken at intervals, whether water quality samples taken every couple weeks, or fifteen minute water levels.
One final type of data not covered so far is the data dictionary. There exist in the NRA a number of dictionaries defining attributes, synonyms, and methods of analysis. The wide range of attributes defined cover such things as chemistry, biology, hydrometry, water supply, and sewage disposal. All of the attributes stored in the database are defined in these and other dictionaries, which are held in WIS.

6. User Interactions

The way the system tools are offered to the user is primarily through menus and a mouse.

The menus themselves have friendly messages on them. Each interaction causes execution of a textual command hidden 'behind' the menu label. These commands can also be typed in directly, or read in from an ordinary file.
All commands, however input, are logged in a file which can subsequently be edited and re-input. This facility can be exploited in several ways. It can be used, for example, to set up batch files to produce standard monthly reports, to simplify the running of applications, and as a way of presenting results as slide shows.

7. Conclusion

This project is in its early stages, with only the barest facilities provided as yet. Many of the common GIS tools have not been provided in this first phase of development. These tools will include data maintenance and manipulation utilities (see, for example, lists in Burrough, 1986). Similarly the DTM still has to be integrated fully into the system. However, it currently uses the same data structures which are proving effective, and therefore the task of integration is not expected to be large.

The time-series data structures are working well, but storage volumes are about twice those needed by the same data in 'unformatted' files. The current system trial will thoroughly test this aspect of the design, as well as giving some

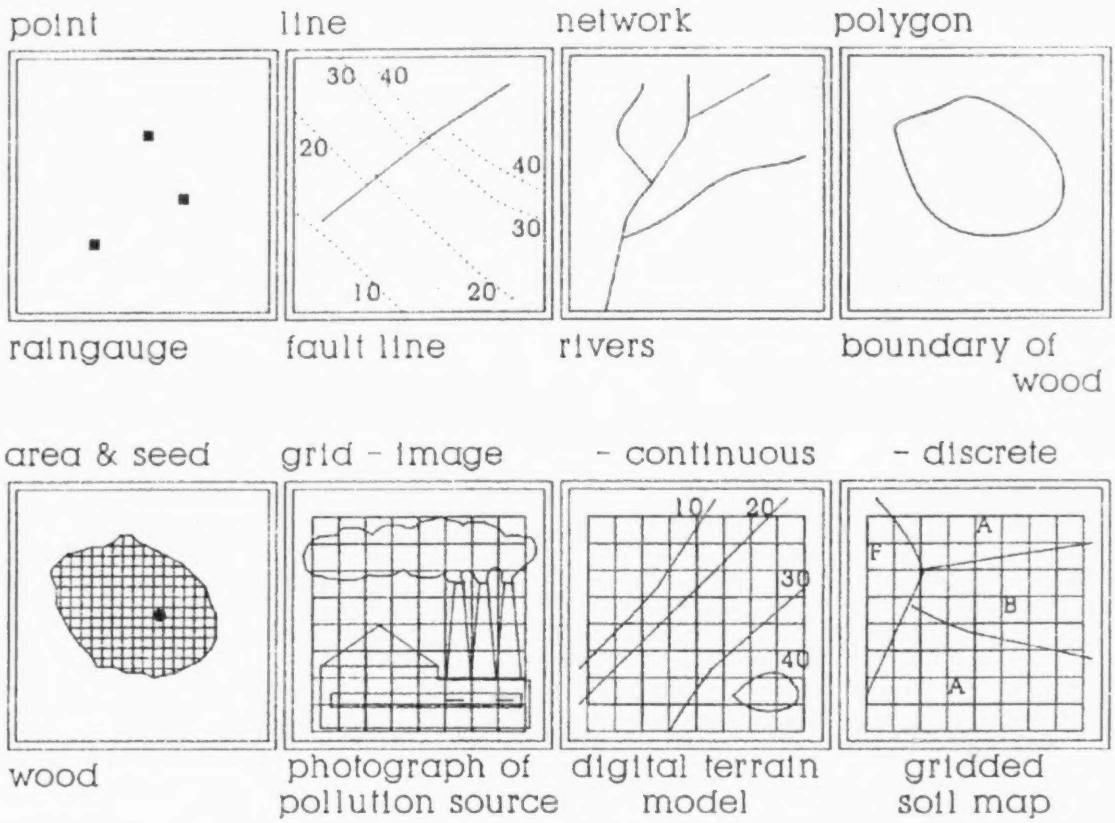
point
raingauge
line
30
40
20
40
30
10
20
fault line
network
rivers
polygon
boundary of wood
area & seed
wood
grid - image
photograph of pollution source
- continuous
10
20
30
40
digital terrain model
- discrete
A
F
B
A
gridded soil map

Figure 3. Spatial data types.

idea of the implications of concurrent update. The overall speed of WIS, with a reasonably large set of test data (35,000 features and 200,000 attribute values), compares very favourably with leading commercially available systems working with much less data.

The software developed so far has, when possible, avoided any hardware and operating system dependencies. Where these have been unavoidable they have been isolated and clearly identified. It has yet to be seen how portable the code is. What is clear is that it is quick and easy to introduce new applications into WIS, and the user and program interfaces are proving very flexible.

Future developments will include work on exploiting further the DTM, and handling true three-dimensional data (see Roper, 1989) - four dimensions including time. This is very important in advancing studies of groundwater.

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Cartographic Modelling of Riparian Buffers

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Abstract

Many jurisdictions in North America require that harvest operations leave vegetation along watercourses. Design of these riparian buffers depends upon the examination and synthesis of terrain, soil and vegetation data from within the vicinity of these watercourses. However, design guidelines are typically simplified due to the lack of site-specific spatial data and/or an effective means to process them. This paper describes the conceptual development of a cartographic model that will make buffer design a rational and systematic process. The model develops solutions for one of the functions of riparian buffers, namely the maintenance of watercourse temperature, by considering a variety of site factors - including slope, watercourse orientation, solar angle and azimuth, and tree height. The paper concludes that the cartographic modelling approach makes riparian buffer design a consistent site-specific process, whereby buffer width varies as relevant site conditions along the watercourse vary. It constitutes an important first step in eventually being able to design riparian buffers on a site-specific basis with a generally applicable procedure.

Introduction
Many jurisdictions in North America require that harvest operations leave bands of vegetation along watercourses to protect non-timber resources. The design of these *riparian buffers* depends upon the examination and synthesis of a variety of factors from within the vicinity of the watercourse, including, terrain, soil and vegetation data. However, design guidelines are typically simplified due to the lack of these site-specific spatial data[1] and/or an effective means to process them.

Processing spatial data has been facilitated in recent years with the advent of geographic information systems (GIS). GIS are an extension of database management systems (DBMS) that deal with spatial data. While DBMS deal exclusively with descriptive data without regard for any locational component, GIS are composed of computer hardware and software that provide a set of tools for collecting, storing, retrieving, transforming, and displaying spatial data (Burrough, 1986).

Maps are a common means of representing spatial data and have long been manipulated in unique ways to derive new information (e.g., overlaying two maps on a light table). GIS also employ basic map manipulation operations that are often based on these manual procedures. In this context, basic map operations are like traditional mathematical operations, in that the sequencing of map operations is similar to the algebraic solution of equations to find unknowns. However, in this case, the unknowns represent entire maps. By extracting and organizing these basic map manipulation operations in a logical manner, the basis for a generalized modelling structure can be developed called cartographic modelling (Tomlin, 1983).

This paper focuses on the development of a cartographic model for one of the primary functions of riparian buffers, namely the maintenance of watercourse temperature for fish habitat, hereinafter called temperature buffers. By identifying the relevant site-specific factors that impact upon watercourse temperature, a cartographic model, implemented on a GIS, can be used to process this data and design temperature buffers using a rational, systematic and quantitative approach.

Relevant Factors in the Design of Temperature Buffers
It is widely recognized that high watercourse temperature has an adverse effect upon fish habitat (Brown, 1972a; Ringler and Hall, 1975; Lee and Samuel, 1976). However, conservative increases in water temperature may actually be beneficial to salmonids in cold, low-productivity streams. Small temperature increases cause an increase in the production of algae and insects which would provide sufficient food to accommodate the increased metabolic activity of fish, resulting in increased fish growth (Moore, 1983).

Several authors (Brown, 1969, Betchta, 1984) have identified the relevant factors which influence watercourse temperature. However, attempts to incorporate these into practical buffer design recommendations for forest managers have typically been so data intensive as to be impractical (e.g., Betchta, 1984). A simple intuitive approach is needed for the prescription of temperature buffers, one that would require a minimum of data input.

To predict temperature changes in watercourses, Brown (1969) developed an equation as follows:

$$\Delta T = \frac{\Sigma H \times A}{P \times C \times Q}$$

where: ΔT = temperature change (°C).
ΣH = net energy flux per unit area (W/m^2).
A = exposed watercourse surface area (m^2).
Q = discharge (m^3/s).
P = density of water (g/cm^3).
C = heat capacity of water (J/g/°C).

If buffers can be designed to maintain post-harvest energy at pre-harvest levels, then Brown's equation can be simplified. Because exposed watercourse surface area (A), water density (P) and the heat capacity of water (C), will not change from their pre-harvest values and because any change in discharge (Q), from cold groundwater seepage related to harvesting will be positive (by serving to further buffer potential temperature increases) then the energy flux (ΣH) becomes the only variable of consequence.

Energy flux is composed of:
(i) net clear-sky shortwave solar radiation,
(ii) net longwave radiation flux,
(iii) evaporative heat flux at the water surface,
(iv) convective heat flux at the air-water interface,
(v) conductive heat flux between bedrock and water; and
(vi) the heat flux advected to a watercourse by ground water seepage.

Over the short watercourse reaches associated with forestry operations, the net effect of longwave radiation, evaporative energy, and convective energy approximates zero (Brown, 1972b; DeWalle and Kappel, 1975; Lee, 1978). Further, during daylight hours, heated water transfers energy to bedrock and after sunset bedrock transfers some of this energy back to the water resulting in a net effect approximating zero (Lee, 1980). In addition, the temperature of groundwater varies only within a few degrees of the mean annual air temperature (Lee, 1980). Because groundwater flow will be the same, or greater, after harvest as compared with before harvest values, it will continue to have a cooling effect on watercourse temperature. It can thus be concluded that the only factor that will contribute to watercourse temperature changes after harvesting is shortwave solar radiation.

Shortwave solar radiation, which is composed of both a direct and a diffuse component, is greatest at noon during which time Latimer (1974) and Reifsnyder and Lull (1965) found that the direct component was approximately 90 percent of the total. Because watercourse temperature increases will be of concern only on clear, sunny days, the diffuse component will contribute little to watercourse temperature increases and, further, riparian strips that protect watercourses from the direct component will also provide protection for part of this diffuse component.

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[1] Spatial data are composed of both locational and descriptive components. Locational components relate data to their geographic position; descriptive components refer to data attributes that provide information about a location.

The primary purpose of the riparian buffer for temperature control then becomes controlling the intensity of direct shortwave solar radiation by maintaining existing shading. The width of this buffer will be referred to as the status quo width. As shown in Figure 1, *it is defined by the location of those trees, whose tips of shadow just touch the near edge of the adjacent watercourse* Trees further away from the watercourse no longer contribute significantly to watercourse shading. Status quo width is influenced by four factors: (i) watercourse orientation; (ii) ground elevation above the watercourse; (iii) height of riparian vegetation; and, (iv) solar angle and direction. All but solar angle and direction can be mapped from topographic and/or forest cover information. But solar angle and direction are simple matters of solar geometry and can be incorporated into cartographic models if time periods critical to temperature increase can be identified.

The risk of watercourse temperature increase is greatest during periods of low flow that also coincide with abundantly available solar energy (i.e., that time of year when the ratio of $\Sigma H / Q$ is maximized). Analysis of historical streamflow data in New Brunswick show that lowest summer flow in small headwater streams occurs during the month of August (Inland Waters Directorate, 1985) and at mid-August, potential shortwave radiation is still approximately 87 percent of its annual maximum (Mateer, 1955). Therefore, the potential for watercourse temperature increase is greatest during this month. Furthermore, the intensity of this shortwave radiation is greatest between the hours of 10 a.m. and 2 p.m. (Beschta et al., 1987). Status quo widths can therefore be calculated for these critical time periods, using a solar ephemeris, riparian slope, vegetation height and watercourse orientation. The maximum width determined during this period will become the buffer width required to maintain watercourse temperatures at pre-harvest levels.

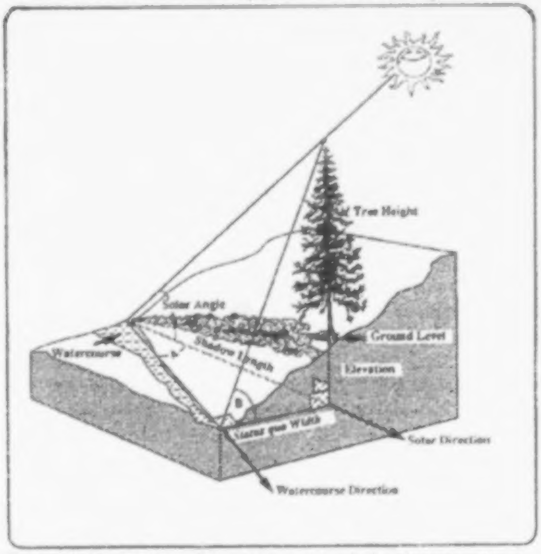


Figure 1. Illustration of the geometric relationships involved with the calculation of status quo width.

Geometric Relationships that Determine Status Quo Width

In order to understand how the status quo width can be derived from mapped data it is necessary to examine Figure 1 in detail. From this diagram, it can be seen that the following relationship exists between tree height, shadow length and solar angle:

tan (SOLAR ANGLE) = TREE HEIGHT ÷ SHADOW LENGTH [1]

or,

TREE HEIGHT = tan (SOLAR ANGLE) x SHADOW LENGTH [2]

It can also be seen that :

sin (A) = STATUS QUO WIDTH ÷ SHADOW LENGTH [3]

or,

STATUS QUO WIDTH = sin (A) x SHADOW LENGTH [4]

where A = the angle between watercourse direction and solar direction.

Finally, from the diagram it can be seen that:

tan (B) = TREE HEIGHT ÷ STATUS QUO WIDTH [5]

or,

STATUS QUO WIDTH = TREE HEIGHT ÷ tan (B) [6]

where B = the angle from the edge of the watercourse to the top of the subject tree.

Substituting Equations [2] and [4] for the right hand portion of Equation [5], gives the following:

$$\tan (B) = \frac{\tan (\text{SOLAR ANGLE}) \times (\text{SHADOW LENGTH})}{[(\sin (A) \times \text{SHADOW LENGTH}]} \quad [7]$$

or,

$$\tan (B) = \tan (\text{SOLAR ANGLE}) \div \sin (A) \quad [8]$$

This indicates that angle B is strictly a function of solar angle and angle A, which is the angle between watercourse direction and solar direction. If these factors are known, then for any tree height an associated status quo width can be calculated by substituting in Equation [6], as follows:

STATUS QUO WIDTH = TREE HEIGHT ÷ tan (B)
= TREE HEIGHT ÷ [tan (SOLAR ANGLE) ÷ sin (A)] [9]

Most of the variables in this equation are readily available from mapped data. As explained in the next section, a grid or raster method was employed in this cartographic model. Because of this, watercourse direction has been limited to the four cardinal directions of north-south, east-west, northeast-southwest and northwest-southeast. Solar direction and angle values can be obtained from a solar ephemeris for the critical period between 10 a.m. to 2 p.m.

during mid-August when streamflow is lowest and solar intensity is still high. Using these data, tangent values for angle B were calculated for both left and right banks of each of the four possible watercourse directions (Table 1). These were later used in processing tree height and elevation data, in mapped form, to calculate status quo widths.

Cartographic Model for the Design of Temperature

Table 1. Tan B Values by Left and Right Bank and Watercourse Direction.

Watercourse Direction	Tan B for Left Bank Buffers	Tan B for Right Bank Buffers
N-S	1.55	1.55
E-W	N/R*	1.85
NE-SW	1.20	3.66
NW-SE	13.66	1.20

*N/R indicates that no value is required because temperature buffers are not established on the north side of east-west direction segments.

Buffers

The Map Analysis Package (MAP) was used to develop the cartographic model which utilized the concept of the status quo width. MAP is a raster-based map processing program developed at Yale University's School of Forestry and Environmental Studies (Tomlin, 1983). The cartographic model was developed by stringing together basic or primitive commands offered by MAP (Figure 2). In some cases, if the command did not manipulate the data in precisely the way desired, it was modified using the available source code. The exact procedures developed are fully explained by Dick (1989) and the reader is referred to him for detailed information. Only an overview of the main procedures used in the cartographic model are presented here as follows:

1. The watercourse was separated into direction segments (N-S, E-W, NE-SW and NW-SE) using the PROFILE and COVER commands in MAP.

2. The bank area along both sides of each direction segment was isolated using the SPREAD (modified) and PROFILE commands.

3. Each watercourse direction segment was processed separately, but in the same manner. The relevant data on the left bank and then on the right bank were synthesized and a temperature buffer prescribed. This was done for all directions except the left (north) bank of those segments running east-west. In the northern hemisphere, the sun always shines from the south during the critical period from 10 a.m. to 2 p.m. and therefore vegetation on the north bank never casts a shadow across the adjacent watercourse. Consequently, no buffer is required on this bank to maintain shading at pre-harvest levels. The general procedure used in all other cases was as follows:

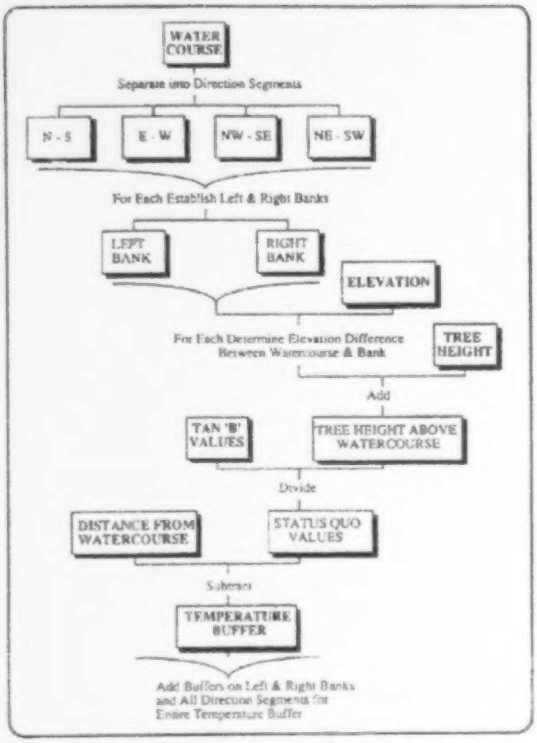

WATER COURSE
Separate into Direction Segments
N - S
E - W
NW - SE
NE - SW
For Each Establish Left & Right Banks
LEFT BANK
RIGHT BANK
ELEVATION
For Each Determine Elevation Difference Between Watercourse & Bank
TREE HEIGHT
Add
TAN 'B' VALUES
TREE HEIGHT ABOVE WATERCOURSE
Divide
DISTANCE FROM WATERCOURSE
STATUS QUO VALUES
Subtract
TEMPERATURE BUFFER
Add Buffers on Left & Right Banks and All Direction Segments for Entire Temperature Buffer

Figure 2. Simplified representation of a cartographic model for the prescription of riparian buffers to maintain watercourse temperature.

(i) Mapped elevation and tree height data were isolated separately, along the left and right banks using the COVER command.

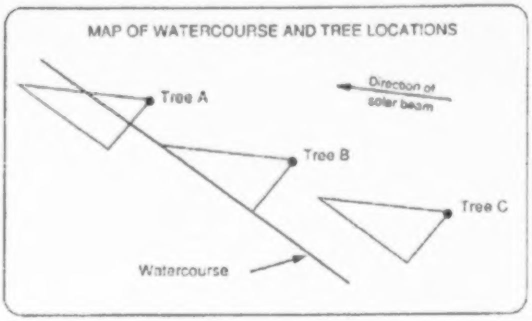
(ii) Elevation differences between the watercourse and the ground surface surrounding the watercourse were calculated using the COVER and SCAN commands.

(iii) Tree height was added to the map of elevation differences to create a map of tree height above the watercourse.

(iv) Tree height was divided by the appropriate tan B value (Table 1) to obtain, for each cell, a status quo width associated with the tree height at that cell. All cells have a status quo width associated with them but, as shown in Figure 3, it is only those cells which have a status quo width equal to their perpendicular distance to the watercourse that actually define the edge of the status quo buffer.

(v) To identify those cells defining the edge of the status quo buffer the SPREAD command was used to create a watercourse proximity map. This map was then subtracted from the map of status quo widths. Cells defining the edge of the status quo buffer became zero (i.e., they have a status quo width equal to the distance from the watercourse); all other cells were eliminated.

4. Finally, buffers for all direction segments were merged to produce a complete temperature buffer for the subject watercourse.



Tree A: - is too tall and/or is too close to the watercourse.
- its associated status quo width exceeds the tree to watercourse distance.
- it does not define the edge of the status quo buffer.

Tree B: - is tall enough and close enough to the watercourse.
- its associated status quo width is equal to the tree to watercourse distance.
- it does define the edge of the status quo buffer.

Tree C: - is too short and/or too far from the watercourse.
- its associated status quo width is less than the tree to watercourse distance.
- it does not define the edge of the status quo buffer.

Figure 3. Illustration of how trees on the edge of the status quo buffer are determined.

Output from this procedure is shown in Figure 4. Generally, the buffers prescribed are surprisingly narrow with the widest occuring on the eastern and western banks of north-south direction segments. For reasons stated earlier, no buffer is prescribed for the northern bank of east-west direction segments. The primary benefit of the cartographic modelling technique is the consistency with which it applies the design rule and buffer width varies as conditions along the watercourse vary.

In a further effort, Santos (1989) incorporated this cartographic model with the ARC/INFO GIS to investigate implementation problems arising from the operational use of the model.

This was done by translating vector data to the raster model and then passing the raster solution back to vector for display.

Conclusions

(i) This paper has detailed the development of a cartographic model for the design of temperature buffers by examining site-specific spatial data from within the vicinity of a watercourse. By scaling the problem down to its essential elements, the prescription of temperature buffers became a problem of maintaining shading at pre-harvest levels along a watercourse. The relevant variables used to achieve this included watercourse orientation, sun angle and direction, vegetation height, and elevation. With cartographic modelling, riparian buffer prescription becomes a consistent site-specific process, whereby buffer widths vary according to relevant site conditions along a watercourse vary.

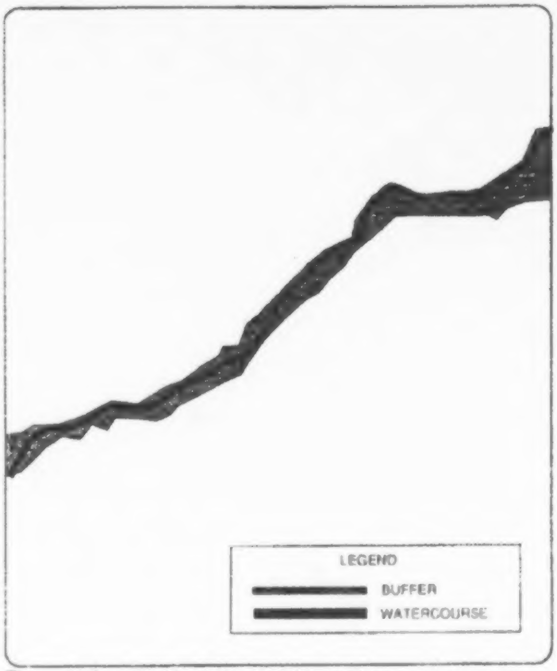


Figure 4. A map of buffers established along a watercourse that maintain water temperature at pre-harvest levels (approximate scale 1:7000).

(ii) While a raster approach was used for this cartographic model, further research is needed to determine if a vector implementation is possible. Work done by Santos (1989) indicates that, while long processing times result from simply translating vector data to the raster model and then passing the raster solution back to vector, a vector solution might shorten the processing time. However, MAP has a very powerful command set and the success of a vector solution will depend upon the robustness of the vector-based GIS that is used.

(iii) In some jurisdictions, the complete absence of site-specific data or the absence of other data in digital form may hinder the implementation of the model. Problems of data availability impact on how the cartographic modelling approach can be used. Generally, there are two possibilities: it can be used either as a management or as an operations planning tool. As a management planning tool, buffers could be prescribed systematically for all watercourses comprising a management unit. A rational and defensible estimate of the quantity of wood removed from the wood supply for riparian protection could then be obtained. This approach is not possible, however, where there is a lack of digital data. As an operational tool, data limitation problems are considerably less. Where detailed inventory data are collected from areas prior to harvest, the model could be used as an aid to prescribing buffers on specific watercourses in harvest areas, using these site-specific data. Regardless of the final implementation strategy, cartographic modelling techniques can contribute to riparian buffer prescription by adding elements of consistency and reliability to current manual procedures.

(iv) Riparian buffers serve functions other than the maintenance of watercourse temperature. There is a need to identify these other functions and to define their critical data elements so that cartographic models can be developed for them. Once done, the models may be simplified by identifying the one(s) that consistently prescribe the widest buffer thereby serving all functions.

(v) This paper has attempted to demonstrate how catographic modelling can be applied to the solution of complex spatial problems. As the use of GIS in organizations moves from providing simple inventory functions to serving the role of a complex analytical tool, the role of cartographic modelling will become more important.

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Three-dimensional Computer Mapping

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Abstract
Earth Scientists have often been frustrated at not being able to visualize or rapidly manipulate property characteristics in a true three-dimensional manner. The new Interactive Volume Modelling (IVM) program from Dynamic Graphics, Inc. provides computing tools for modeling, displaying, manipulating and analyzing property values, located by X-, Y- and Z- coordinates, in three dimensions. This technology enables users to rapidly gain a much better understanding of internal geometric and property relationships occurring within and/or between single and multiple layers.

Introduction

Earth scientists have often been frustrated with their inability to visualize or rapidly manipulate property characteristics in a true three-dimensional manner. The new Interactive Volume Modeling (IVM) program from Dynamic Graphics, Inc. provides computing tools for modeling, displaying, manipulating and analyzing property values, located by X-, Y- and Z- coordinates, in three dimensions. This technology enables users to rapidly gain a much better understanding of internal geometric and property relationships occuring within and/or between single and multiple layer frameworks.

Modeling

The modeling procedure in IVM takes scattered data points of a physical property value (e.g., porosity, salinity, chemical concentration, etc.) and calculates a three-dimensional grid. This grid represents the modeled distribution of the property in three-dimensional space.

The three-dimensional grid can be calculated by one of three methods:

- The first method calculates the grid throughout a volume defined by the inputs scattered data distribution or throughout a volume defined by the user.
- The second method restricts the calculation laterally to the area enclosed by a predefined polygon, i.e., limits in X and Y, but not in Z.
- The third method allows the user to use previously calculated faulted or unfaulted two-dimensional structural surfaces as hard boundaries which limit the modeling process in X, Y and Z. This third method enables the user to calculate, for example, a model of porosity or permeability within a zone while not allowing the model to be influenced by measured values in underlying or overlying layers. This procedure provides a much more realistic model of property variations within a zone.

A newly developed strataform gridder is currently being tested. This gridding procedure is designed to enhance lateral continuity within layers. Interpolated property values are calculated in a manner that more closely resembles the geometry of the geological processes which formed the layers, i.e., conformal to a boundary. The calculated property model can be conformed to the shape of either an underlying or overlying structural surface, or both. The user is given control over the degree of horizontal continuity to be established. The results thus far have been promising, especially with thin laterally continuous or discontinuous beds.

The procedures for calculating property models are based on a three-dimensional extension of the robust two-dimensional gridding techniques used by Dynamic Graphics' Interactive Surface Modeling (ISM) program. These techniques utilize a variation of the minimum tension surface algorithm. Users are not restricted to using only IVMs modeling procedures. Three-dimensional grids calculated elsewhere can be brought into IVM with import and export subroutines supplied by Dynamic Graphics.

Display

- Once built, the user can manipulate the display file in numerous ways to better understand the internal relationships contained within the model:
- The model can be sliced along the X-, Y- or Z- axes at specified intervals,
- The model can also be sliced first along Y, then X, then Z, or any combination thereof to produce color-filled sections along all three sides,
- The model may be rotated to any user specified azimuth and inclination, or may be 'grabbed' and turned to any desired orientation.

While slicing and rotating, the user can select a particular range of isovalue surfaces to be displayed, or not displayed. For example, the user may decide to display only those porosity values between six (6%) and nine (9%) percent, or to display all porosity values except those between six (6%) and nine (9%) percent.

Alternatively, the user can use the chair mode display, which cuts out only a piece of the model parallel to the X-, Y- and Z- axes:

- The chair area is bounded by vertical walls (X- and Y- axes) and a horizontal floor (Z- axis) on which are displayed color-filled sections of the property distribution,
- The user can interactively adjust the width, depth and height of the area along any axis.
- The user can elect to display, within the chair area, a range of isovalue surfaces.to give the appearance of being extruded into the missing volume.

The user can also rapidly 'flicker' between two different property models which gives the effect of superimposing two models. The user loads one model and selects the proper orientation that best displays the property distribution. Then, the second model is loaded with the same display parameters. Now, with the touch of a single key, the user 'flickers' between each display as rapidly or as slowly as desired. This is very useful for comparing distributions of such important properties as porosity and permeability.

At any point, the user can access the program's internal Color Table Editor to define any combination of colors necessary to vividly illustrate a concept.

Analysis

IVM contains a full complement of the extensive analytical capabilities found within Dynamic Graphics' two-dimensional mapping package, Interactive Surface Modeling (ISM). These analytical capabilities include the following:

3-D Volumetrics:

Volumes can be determined for the entire model, between isovalue surfaces, within a surface polygon, between two-dimensional structural surfaces, above and below specific depths or for any combination of these possibilities. A typical problem could be "Calculate the pore volume between six (6%) and nine (9%) percent porosity, within Zone B, inside of Lease J and above the oil/water contact W."

3-D Trend Gridding:
Three-dimensional trend gridding is available for polynomial surfaces between 1st and 14th order. These trend grids can be subtracted from the associated property grids to calculate three-dimensional residual grids, which can be used for display or volumetric calculations.

3-D Grid Operations:
IVM contains three-dimensional extensions of nearly all of the standard grid operations found in two-dimensional mapping packages. A property grid can be modified through such mathematical operations as addition, subtraction, multiplication or division by a constant or another property grid. Trigonometric, log (base 10 and base e), antilog and exponentiation grid functions are also available. These grid operations can be used to compare models or analyze changes in a particular model over time. Property grids, for example, can be subtracted and volumetric calculations performed on the resultant residual grid. This quantitative information can be used to document and carefully evaluate time varying changes within various models.

Data Extraction:
Data can be extracted from the three-dimensional grid in the form of individual data points or as two-dimensional grids. For individual points, the user must supply X-, Y- and Z-coordinates for the locations at which values will be back-interpolated from the property model. Two-dimensional grids can be extracted along a slice through the volume or at node locations defined by a previously calculated two-dimensional grid. The extracted two-dimensional grid values can be either the discrete back interpolated values or the column averages between two structural surfaces. The data extracted from three-dimensional grids can be used for simulation purposes, additional analyses or for standard two-dimensional computer mapping.

Geologic Modeling

A basic geologic modeling capability enables the user to build a three-dimensional multiple layer framework with property values modeled within each layer. This new capability is useful for large scale regional studies of basins, as well as for small scale detailed studies of individual oil reservoirs.

The user builds a framework, using previously calculated faulted or unfaulted two dimensional grids as layer boundaries. Within each layer, property models can be calculated with either the standard or strataform gridder and then combined into a single display file. The entire model can be rotated to any orientation and sliced along any axis. Along the slice faces, the different layers and their property variations can be displayed as color-filled sections. The chair mode display can be used to remove a part of the entire model. Any selected layer can be turned on and displayed within the chair void. This layer is not affected when dimensions of the chair void are changed. Successive layers can be turned on, giving the effect of rebuilding the model one step at a time within the chair void,providing considerable insight into three-dimensional relationships contained in the model.

Within the model, any number of layers can be turned off. This creates a void between adjoining layers. The user can zoom into this space to closely examine geometric or property relationships inside the model. Color-filled elevation contours can be displayed on top of individual layers. Selected units can be color-filled with solid lithology colors to visually enhance boundary relationships between layers. Volume calculations can be performed on any part of any layer.

Applications

IVMs three-dimensional modeling, display, manipulation and analytical capabilities have been used in the earth sciences (including geological, geophysical, atmospheric, oceanographic and environmental disciplines) to solve and understand numerous problems. The range of possible applications of IVMs three-dimensional visualization capabilities is very broad, as evidenced by the examples described below.

Geology and Geophysics

In the geological and geophysical disciplines, IVM is being used to provide a much better understanding of persistently troublesome problems. For example, IVM has been successfully used to display, verify and edit three-dimensional seismic velocity files. This is important for subsurface exploration because velocity files are critical to converting interpreted seismic data to depths within the earth's crust. Typically, this verification procedure requires several months of intense study using numerous cross sections and contour maps through calculated models. Geophysicists have used IVM to study and verify the internal consistency of calculated velocity models and their correspondence to geological data. The time required for these studies has been significantly reduced from months to hours.

Petroleum

Geologists and petroleum engineers are using IVM to better understand the characteristics and behavior of hydrocarbon reservoirs, in an effort to improve oil and gas production. A thorough understanding of a reservoir's internal geometry and the three-dimensional distribution of properties within it are critical to successful production and recovery activities. In one reservoir, a study of the three-dimensional distribution of permeability barriers revealed that one sand layer was not being affected by long-term steam injection and that significant amounts of hydrocarbon were being left behind. In another reservoir, IVM was used to demonstrate that injected steam was bypassing an important layer and quickly moving to another. Other studies evaluated the three-dimensional distribution of permeability within individual reservoir zones. Within certain zones, previously unrecognized tilted permeability barriers were identified and studied with IVM. This knowledge could lead to changes in established reservoir management drilling programs and increase oil production.

Petroleum engineers try to understand the behavior of hydrocarbon reservoirs by running costly and complex simulation programs which predict reservoir response through time. These programs require complicated data for input and produce large volumes of three-dimensional data as output. IVM is being used with reservoir simulators as both front-end and back-end processors. As a front-end, IVM is used to build and verify geometric relationships of a reservoir's internal plumbing. The distribution of important properties such as porosity, permeability and hydrocarbon saturation is also validated. As a back-end, IVM is used to display models calculated at different time steps during the simulation run. With IVM, reservoir engineers can quickly study the predicted changes over time of such properties as oil saturation and reservoir pressure.

Environmental
In the environmental arena, IVM is being used to visualize the distribution and movement of pollutants within aquifers, and to verify the correctness of three-dimensional data being produced by both groundwater and atmospheric models. IVM is being used at several hazardous waste sites to help define the distribution of such chemical contaminants as PCB and PCE within local ground water systems. IVM calculates the total amount of contaminant present and determines the volumetric distribution of critical concentrations. The geologic properties of local groundwater systems can be evaluated in three dimensions, thereby providing information critical for the design and management of effective clean-up efforts.

In all instances of applying IVM, users quickly gained a much better understanding of the calculated results. Previously unknown errors in one model were immediately obvious when the results were displayed in IVM. The three-dimensional visualization of unrealistic results allowed engineers to quickly identify and correct the subtle software problems. For some time, scientists had been evaluating a groundwater model by vertically averaging the calculated data and displaying the results as a two-dimensional contour map. Once this model's results were displayed with IVM, an unrecognized and unexpected steep vertical gradient in predicted particle dispersion was identified.

Atmospheric
IVM has been used to display the results from a complex atmospheric model which calculates the distribution of ozone over the northeastern United States. Various time steps during a 24-hour period were used to show the significant increase in ozone concentration over time. The largest amounts of ozone were related to metropolitan and industrialized areas.

IVM provides atmospheric scientists with sophisticated three-dimensional capabilities that can be used in numerous ways to verify their models and to measure the impacts of different model scenarios. For example, data sampled in the atmosphere from planes or balloons can not only be compared to the modeled values at those same discrete X-, Y-, Z- locations, but their spatial relationship with the complete three-dimensional model can be investigated. This can be used to determine if the sampled data location was near the center of a chemical plume or near the edge. It can also be used to analyze situations when the sampled data differs from the modeled data by showing the location of the emission points that were used in the model.

Various model scenarios can be tested using IVM. For example, chemical concentrations can be calculated above different population zones using the output from the base run of the atmospheric model. The input data can be changed to reflect various legislative scenarios, the atmospheric model rerun and IVM can calculate the new volumes of chemical concentrations above the same population zones.

Oceanography
IVM has been used for oceanographic studies of salinity and temperature variations within certain bodies of water. Salinity data from the Chesapeake Bay was modeled and displayed to show the effect over time of fresh water incursions due to storm run-off. Volume calculations were conducted for various salinity concentrations during the period of time required for conditions in the Chesapeake Bay to return to normal. Temperature, density and salinity variations in certain ocean areas have been studied and volumes calculated for water at various temperatures. IVM provided insight into relations between temperature distributions and strength of water currents.

Summary
IVM's modeling, display, manipulation and analytical capabilities are indeed applicable to a large number of earth science problems. Scientists and engineers can now study and analyze three-dimensional geometric and property relationships in ways that previously were impossible with two-dimensional mapping.

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Water Resource Applications of GIS in the State of Idaho

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Abstract
The Idaho Department of Water Resources (IDWR) is Idaho's lead agency for remote sensing and GIS. IDWR has several active GIS projects involving water resources. Most of these projects require capturing data layers, building data bases, and analyzing data on a state-wide basis. Over the next five years, IDWR anticipates bringing on-line about 30 gigabytes of data designed specifically for GIS applications.

Introduction

In 1978, the Governor of Idaho established the Idaho Image Analysis Facility within the Idaho Department of Water Resources (IDWR) as the lead state agency for remote sensing and GIS. Lead status authorizes IDWR to cooperate with other state agencies, federal agencies, and private sector firms to promote and support applications of remote sensing and GIS in Idaho. In order to carry out the Governor's mandate, IDWR staff use a variety of software on several platforms to carry out remote sensing and GIS projects, several of which involve water resources. The purpose of this paper is to show how widely GIS technology has been applied to water resource issues, even in a state of relatively modest means, by outlining both the projects and the equipment used at IDWR.

Hardware and Software

IDWR personnel use a variety of software running on several different platforms for GIS work. ARC/INFO software is the GIS workhorse, running on two VAXstation 3200 workstations, and on five PCs: two 80286s and three 80386s. Other software includes ERDAS GIS software, DBASE III+, and in-house software tailored for specific, high-volume work in digitizing and subdividing the Public Land Survey System (PLSS), then overlaying the PLSS onto thematically classified Landsat images. The ERDAS software runs on an 80386 platform, the DBASE III+ runs on several PCs, and the in-house software runs on a MICROVAX III. Plots are generated using two 36" Bruning/Nicolet pen plotters, one of which is connected to the MICROVAX, and one to a '386 PC. All the hardware platforms are networked with ETHERNET to speed communications.

Large volumes of data require large disk drives. The VAXstations have 950 Mb of hard disk each, and one 650 Mb erasable optical disk. The '386 PCs have 300 Mb hard drives, and the '286 PCs have 135 Mb and 120 Mb of hard disk. The MicroVAX III has about 950 Mb of hard disk.

Projects

The water resource projects can be divided conveniently into surface water projects and groundwater projects. Surface water projects include assembling data bases on which to prepare a comprehensive rivers plan, tabulating the number of irrigated acres in each quarter-quarter section of agricultural land of the Snake River Basin, annually estimating the amount of water used by irrigated agriculture the state, and mapping the irrigated land in the tri-state area of the Bear River Basin. The work for the rivers plan is largest and most ambitious of the projects.

The Comprehensive Rivers Project

The comprehensive rivers planning project was motivated by a desire on the part of the Idaho Legislature to establish state control of licensing of hydro-power rights on Idaho rivers. In order for the Federal Energy Regulatory Commission (FERC) to delegate this authority to a state, such a state-wide, comprehensive plan must be in force. IDWR management reviewed the enabling state legislation, and identified forty applicable data themes, of which twenty-one were immediately important to address issues specified by the Legislature. These twenty-one themes include the Public Land Survey System, the hydrographic network, land ownership (private, state, and federal agency), political boundaries, hydrologic unit boundaries, existing dams, potential dam sites, active FERC sites, recreational use of river reaches, fishery habitat of river reaches, federal wild and scenic rivers, state interim-protected rivers, land use, transportation, mining claims, proposed timber sales, archeological sites, special management areas, grazing allotments, groundwater management areas, and potentially irrigable land. The data capture is estimated to require about ten worker-years of effort, and about thirty gigabytes of storage.

While the rivers project is daunting in scope, many of the data are needed for other projects, or more correctly, other projects are capturing data that are needed for the rivers project. For example, a digital version of the PLSS is being generated for the Snake River Basin Adjudication (SRBA).

The Snake River Basin Adjudication

The SRBA project covers about 72 000 square miles, almost 90% of Idaho. A digital version of the PLSS is an integral part of the project. IIAF is digitizing the PLSS section corners and subdividing the sections into quarter-quarter sections, government lots, mining claims, and homestead entries. Thus far, IDWR has assembled complete, state-wide, digital coverage of PLSS sections, and subdivided about half of them. IDWR uses the PLSS to tabulate the number of irrigated acres within each quarter-quarter section and government lot by overlaying the land net on top of thematically classified Landsat images (Morse et al. 1990).

The PLSS data have several actual and potential applications in addition to that of the SRBA. The subdivided sections have legal designations (e.g., T4NR13W12NWSE) that are used as the legal description for, among other things, the locations of Idaho water rights. Thus, the results of a data-base query on the master water-rights file can be converted into a thematic image showing water-rights information, which, in turn, can be merged with either a Landsat FCC image or a classified Landsat image to identify both unpermitted irrigation and water rights not put to beneficial use.

The Bear River Compact Depletion Study

Three states, Idaho, Utah, and Wyoming share the waters of the Bear River under the provisions of the Bear River Compact. IDWR, in cooperation with the two other states is working to equitably distribute and monitor the unallocated water of the Bear River. Since almost all unallocated water is used by irrigated agriculture, accurate mapping of irrigated lands using remote sensing and GIS is a necessary first step in equitable allocation.

Each state has mapped irrigated agriculture as of 1976 in their portion of the basin using Landsat digital imagery and, at IDWR, high altitude photography. The resulting classification was converted to an ARC/INFO coverage. IDWR combined this land classification with the PLSS to report the total number of agricultural acres in each section in the Idaho part of the basin.

The next step will be to compare 1990 Landsat data with irrigation as of 1976 to determine the depletion to Idaho's water allocation. The depletion is determined not by just acreage totals but also by other environmental factors affecting the use of irrigation which differ throughout the basin. This monitoring will done at regular intervals agreed upon by the three states.

Groundwater Vulnerability
Historically, the Idaho Department of Health and Welfare (IDHW) has had responsibility for water quality in Idaho. As part of that responsibility, IDHW recognized the need for a means of assessing and mapping the vulnerability of the Snake Plain aquifer to chemical contamination. IDHW and IDWR are cooperating to that end. IDHW modified the EPA DRASTIC system for Idaho, and contracted with IDWR for land cover data, digitizing, analysis, and map products; with USGS for depth-to-water data; and with the U.S. Dept. of Interior, Soil Conservation Service, for the STATSGO soils data. IDWR digitized the STATSGO data, and worked with an IDHW soil scientist to assign weighting factors to the soils, which were composited with the other data layers to generate a series of maps 1:100 000 maps showing four classes of vulnerability. This work covers the entire 20 000 square miles of the Snake River Plain, and is intended as reconnaissance rather than as site-specific data.

Soil Corrosivity
In cooperation with IDHW, IDWR is analyzing and mapping soil corrosivity for the full state. The project was motivated by the need to replace underground storage tanks that are leaking hazardous liquids. IDWR used the digital STATSGO soil data, and accessed a large relational data base associated with the soils to extract pertinent data on soil chemistry. The resulting analysis delineated five classes of soil corrosivity. IDWR delivered a state-wide map at 1:1 000 000 and state-wide quads at 1:250 000 to IDHW. The map is being used to set priorities for removal and replacement of underground storage tanks. Additional benefits of this project are the completion of a state-wide soils data layer, and access to the STATSGO soils data base.

Bruneau Snail
The Bruneau snail lives in hot-spring pools of Owyhee County in southwestern Idaho. The U.S. Fish and Wildlife Service (USFWS) is considering whether the snail should be designated as an endangered species. IDWR is working cooperatively with USFWS to try to understand the impact of groundwater-source irrigation on the water levels in the pools. The pools are located in the Bruneau groundwater management area. IDWR is assembling data layers and data bases for GIS analysis to help determine the best management strategy to allow people and the snails to successfully coexist. The data being captured include depth to water, spatial distribution of irrigation systems, agricultural/non-agricultural land cover, sub-surface geology, locations of artesian wells, climate data to assess recharge potential, the location and characteristics of geothermal resources, water rights data including points of diversion and historical patterns,surface water hydrology, and groundwater quality and quantity.

Water Use Data
IDWR is responsible under contract to the U.S. Geological Survey to compile annual statistics on Idaho water use. IDWR concentrates on water use by irrigated agriculture because about 98% of Idaho water use goes into irrigation. The estimate is generated by putting an estimate of irrigated acreage into an evapotransporation equation. The estimation procedure provides a statistically generated estimate of irrigated acreage as well as the precision of each estimate.

IDWR uses several digital data layers and GIS processing in the estimation process. These data include hydrologic unit boundaries, county boundaries, the section corners of the PLSS, boundaries of the irrigated stratum, and the state-wide tic file 7.5 minute USGS quads. IDWR digitized the hydrologic unit boundaries and county boundaries from 1:100 000 quads. The irrigated stratum was digitized from interpreted 1:250 000 Landsat FCC images. The file of 7.5 minute quad corners is used to register all ARC data layers, and as a template to identify quad locations. All files are ARC/INFO coverages.

IDWR composites all the above data layers and uses an ARC/INFO AML written in-house program to generate a 5% random sample of irrigated sections in each hydrologic unit in each county. The sampled sections are processed in a methodology modeled on that described by Holko and Sigman (1984). The data generated for each hydrologic sub-unit are output from ARC/INFO, and entered directly into dBASE III+ for efficient management. The process is described in more detail by Morse (1990).

The next step is to digitize the sampled sections into an ARC coverage. Each digitized section includes boundaries of irrigated fields and the section boundaries. IDWR generates INFO reports on the number of irrigated acres in each sampled section for each hydrologic subunit. These statistics are the raw data for the estimation process.

Hydro Power Databases
Idaho, along with Washington, Oregon, and Montana, is participating in a project funded by the Bonneville Power Administration to use GIS in analyzing alternative sites for energy generation. Idaho is concentrating on hydro-power sites.

The project has several aspects. First is an inventory of all state-wide digital data in Idaho, with an assessment the usefulness of including them in a GIS. Next, is the production of a prototype analysis on an actual hydro site. This is designed to help pinpoint what other data are needed, and whether the data used are at the necessary level of detail. Then, critical data on hydro sites are to be compiled and quality-controlled.

Summary

The Idaho Department of Water Resources has an active program for remote sensing and GIS analysis. As the lead state agency for remote sensing and GIS, IDWR cooperates on a variety of projects with other state and federal agencies. Several of those projects deal with water resource issues: surface water, groundwater, water quantity and water quality. The large volume of work being done in GIS by IDWR is made possible, in part, by the fact that many of the data being analyzed are common to several projects.

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Managing Resource Conflict

Session B1
GIS for Fire and Pest Management

Flexible Analysis Through the Integration of a Fire Growth Model Using an Analytical GIS

Modelling Stand Vulnerability to Spruce Budworm Attack

Post-fire Recovery of Riparian Resources on the Idaho Batholith; a GIS Analysis

GIS'90 Symposium

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Flexible Analysis Through the Integration of a Fire Growth Model Using an Analytical GIS

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Abstract

Forest managers use specialized computer software for their data requirements. In inventory and cutting operations, a general purpose custodial GIS serves the purpose, while in forest fire operations, specialized fire growth models are often employed. In an operational setting, however, these management needs are frequently interrelated, but linking and sharing data sets between programs is often cumbersome and inefficient. The integration of specialized software within the framework of an analytical GIS would provide forest managers with a comprehensive management tool. To illustrate this point, an analytical GIS and a forest fire growth model are integrated and the flexibility which this provides is illustrated.

Introduction

It is well known that forest fires are an important process in maintaining and improving wildlife habitat. However, the impacts to man in regards to fire damage and the costs of controlling and managing forest fires can be extremely high.

As witnessed in Yellowstone National Park in 1988, as well as the Province of Manitoba in 1989, the cost of fire damage and mitigation is extremely high. The Yellowstone fires alone cost $145 million to combat (Arno and Brown, 1989), while in Manitoba fires burned 2.6 million hectares, with many towns being evacuated in advance of the fire fronts.

It is in this context that fire managers operate. These managers also contend with dwindling budgets and escalating operational costs and must turn to more effective decision support tools.

Over the past several years, through the proliferation of computer technology at the operations level, foresters of a wide variety of interests have applied and developed software to assist in their daily operations. One particularly significant type of software that has seen wide acceptance is a Geographic Information System (GIS). GIS has seen active use in many areas including inventory, harvest management and silviculture, to name a few.

Forest fire managers have also employed GIS for operations such as fuel mapping, weather condition mapping, and fire danger rating. In regards to actual fire growth modelling, sophisticated and specialized software have been developed around fire behaviour research. Both a GIS and a fire growth model have much to offer the fire manager, but having the them operate together with a two-way link to share common data sets creates a powerful new tool.

To these ends, a pilot project was undertaken to integrate a fire growth model in a GIS framework. A study area was chosen, and relevant data was gathered for an area in Northern Ontario. Data base testing was undertaken to assess the technical and operational aspects of the GIS and fire growth model link.

Project Objectives

The project objective was to use an existing analytically oriented GIS, and link it with an existing fire growth model. Research and development for the project was undertaken by TYDAC Technologies in the fall of 1989, together with the Ontario Centre for Remote Sensing (OCRS).

To test the overall utility and applicability of the integrated GIS and fire growth model, a fire operations case study setting was chosen which involved the personnel of the Research and Development Section of the Aviation and Fire Management Centre, Ministry of Natural Resources (AFMC), in Sault Ste Marie, Ontario.

System Description

The Spatial Analysis System (SPANS), of TYDAC Technologies Inc. in Ottawa was the GIS software employed in this study. SPANS consists of six standard modules, which constitute a complete GIS workstation. SPANS has powerful analytical and data integration capabilities which were essential to the technical requirements of this project.

Three SPANS modules are of particular importance: Core, Raster Interface and Vector Interface. The Core module contains all of the display, overlay and manipulation capabilities which enable SPANS to work with vector, raster and its own quadtree data. Projection transformation between all the major projection types is also available in the Core module.

Data interfaces have been developed in the two interface modules, such that SPANS can accept data from raster and vector environments through data transfer standards. The Raster Interface module allows for the transformation of raster data from raster Image Analysis Systems (IAS), as well as grid based GIS. The Vector Interface module allows for the translation of vector data in standard data exchange formats such as SIF, DLG, DXF, ARCEXPORT, etc., into SPANS vector format.

The fire growth model software was provided by two Canadian companies which have expertise in the area of fire applications. Integrated Forest Systems (IFS) of Maniwaki, Quebec and R/EMS Research of Fredericton, New Brunswick were chosen. Both IFS and R/EMS undertook joint development with TYDAC Technologies Inc., to provide smooth two-way interfaces between SPANS and their respective models. Both models use cell or grid data, and are based on cellular diffusion processes.

The IFS and R/EMS data operate in the context of classical fire behaviour research, incorporating the theories of the Canadian Forest Fire Behaviour Prediction (FBP) System. The R/EMS model can be adapted to other types of fire diffusion theories.

Both models require three sets of input data: FBP forest fuel types, weather parameters, and digital elevation data. SPANS acts as a data capture front-end to the fire growth models, and it is SPANS which provides the required data for a given area (window) of interest.

The integrated GIS/fire growth models run on standard PC based microcomputer hardware.

Study Area

To address specific fire management issues in the province of Ontario, and given the limited availability of critical data sets, a number of study areas were chosen which encompassed portions of, and the entire MNR North-Central Fire Region. These different study areas were chosen to take into account the variation in the scale and resolution which fire managers deal with on a day-to-day basis.

The three study areas are as follows:

(1) the entire North Central Fire Region, which encompasses an area of nearly 100 000 square kilometers (Figure 1);

(2) a subset of the region encompassing 4 National Topographic Series (NTS) map sheets (these are 42E - Longlac, 42L - Nakina, 52I - Armstrong, and 52H - Nipigon), total area of around 45 000 square kilometers (Figure 2); and

(3) a smaller subset of the North Central Fire Region encompassing 4 Ontario Base Mapping (OBM) Series map sheets (these are sheet numbers 32539, 32540, 33539 and 33540), (Figure 2).

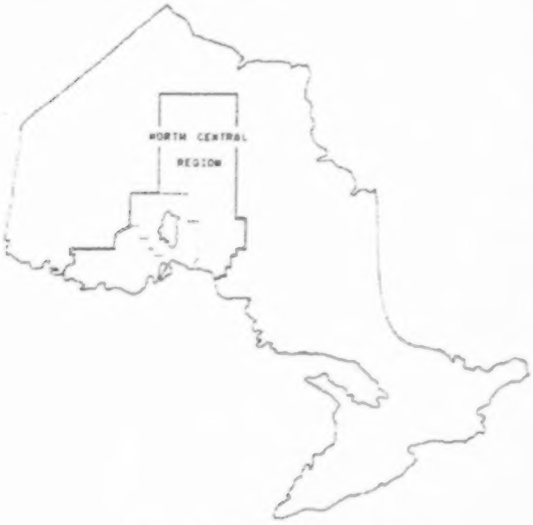

Figure 1. North-Central Fire Region

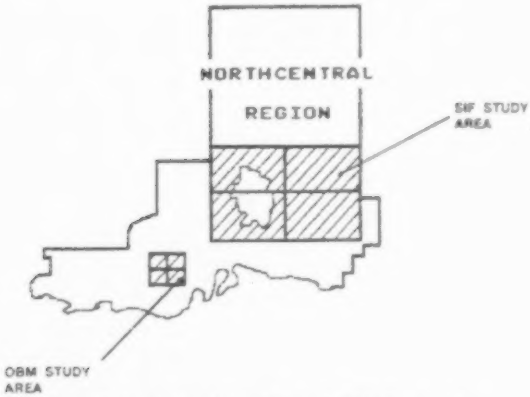

Figure 2. Location of the SIF and OBM Study Areas

Data Sources

There are few comprehensive sources for the digital data required for this project. Thus, classified Landsat Multi-Spectral Scanner (MSS) data constituted an essential source for forest fuel type data, since detailed forest inventory data is for the most part not yet available. These data were provided for the entire North Central fire region by OCRS.

Table 1 summarizes the data types and sources that were obtained for the three chosen study areas. In SPANS, three separate data bases were established to preserve and optimize the different data resolutions that were inherent in the source data.

Operational Demonstration

A workshop was conducted in the AFMC offices which focussed on the informational needs of the fire personnel, from the perspective of both a GIS and an integrated GIS and fire growth model. Several days of weather and lightning strike data were obtained prior to the workshop and brought into SPANS in preparation for analysis. The data was selected from the 1989 fire season, from which July 26 was chosen to be used in the workshop simulation.

In the scope of fire operations, different levels of informational detail are required. As indicated in Table 1, the data sets that fire managers commonly deal with are a combination of different sources (raster, vector and point data), and different spatial resolutions/scales. This situation is dictated by both the nature of available data, as well as operational requirements.

The entire North Central Fire Region data base was first manipulated in SPANS to display Canadian Forest Fire Weather Index (FWI) codes and indices as related to weather observations. Also, Fire Behaviour Prediction (FBP) System defined Rate of Spread (ROS) condition was calculated. Graphic overlays were performed of selected data sets. For instance, lightning strikes were overlaid onto a map of Duff Moisture Code (DMC). A lightning strike density map was generated from the July 26 data set of nearly 6500 points for that date. This map was then compared to the map of DMC.

Two-map cross-tabulations between ROS and forest fire fuel types were calculated for the entire North Central Fire Region, and produced in an ASCII report. Airport locations were entered into SPANS, and distance buffers were created based on 15 minute flying intervals up to 1 hour. This map was then compared to the ROS map to see if there were any potential hazard areas which were not covered adequately by air.

The testing of the combined SPANS and fire growth model involved the use of the OBM data. These data were of sufficient spatial resolution and accuracy to be commensurate with the scale and scope required by the forest managers for fire growth modelling.

Initially, a study area was selected which was in the order of 10 x 10 kilometres, or the size of one OBM map sheet. Once the window on the data base was defined, raster representations of the forest fire (FBP) fuel types, as well as the DTM data were produced by SPANS. The fire growth model then accepted the data and brought both data layers into its own internal raster structure. Weather data concerning wind speed and direction was then entered along with the Fine Fuel Moisture Code (FFMC). A number of fires were then ignited and their growth for a period of time was modelled.

DATA ELEMENT	TYPE AND RESOLUTION	SOURCE
(1) North Central Fire Region:		
Forest Fuel Types	Raster Landsat Data (200m)	OCRS Classified
Weather Parameters	Point (28 stations)	ASCII Text File (MNR - AFMC)
Lightning Strikes	Point (with polarity)	ASCII Text File (MNR - AFMC)
(2) NTS Area:		
Forest Fuel Types	Raster Landsat Data (50m)	OCRS Classified
NTS Map Sheets (1:250,000)	Vector Intergraph SIF Data (42E, 42L, 52I and 52H map sheets)	Energy, Mines and Resources
Digital Terrain Model (DTM)	100 Metre Grid Data (42E map sheet only)	Raster Scanning
(3) OBM Area:		
Forest Fuel Types	Raster Landsat Data (50m)	OCRS Classified
OBM Map Sheets (1:50,000)	Vector Arc/Info DLG Data (32539, 32540, 33539 and 33540 map sheets)	Ministry of Natural Resources
Digital Terrain Models (DTM)	50 Metre Grid Data Resources	Ministry of Natural

Table 1 - Types and Sources of Data for the Three Study Areas

The fire growth model result was then exported back to SPANS, in the form of a raster file which is classified into burn intervals of a given time interval, (i.e., every 15 minutes, or every half hour). Once in SPANS, the burn raster was then converted back into quadtrees for analysis. The burn result was displayed in SPANS, and OBM contour information was graphically superimposed. Area analyses and two-map cross-tabulations were performed on the burn raster, which provided information on the effect of the fire on forest resources over time.

Conclusion

The three study regions that were prepared for this study provided the ability to examine the various types of available data and how they would perform in an operational setting, where time is an important factor. Issues were raised of data resolution and accuracy in regards to processing time constraints for the SPANS and fire growth model burn analyses. Maintaining different data bases, as was witnessed in this project, appears to be the most effective solution in regards to using the most appropriate data base for the required resolution.

Much of the information that is required by fire operations such as the AFMC, are based on forecasts in which two to five day predictions of weather conditions and fuel hazard areas are vital to the proper allocation and placement of fire fighting equipment. SPANS is able to take the forecast data and quickly provide regional overviews of weather and fuel conditions. Batch processing files can be set-up to handle repeated requests, which can be performed overnight. GIS capabilities are also of importance to fire history analysis.

The interchange of data between SPANS and the fire growth model is subject to further revision and streamlining. The export process out of SPANS will be developed to incorporate a menu that will accept weather and other relevant data, and write out a formatted text file which will be imported into the fire growth model. Raster data translation and computational speed will be improved through the use of paged rasters which groups the raster into segments which are indexed, and SPANS represents a GIS platform suitable for the capture and integration of the complicated and diverse raster, vector and other supporting data sets that were encountered. More importantly, the quadtree data structure offers significant data storage efficiency and computational speed in performing many of the required analytical operations.

The combined SPANS and fire growth model seems to be able provide the fire operations specialist with analytical and information reporting capabilities that were either not available, or limited in regards to the ability to integrate and manipulate the different data sets that they are currently using in their work.

As mentioned above, the integrated SPANS and fire growth model operates on the same inexpensive and readily available PC-based hardware platform, and is capable of accessing and processing existing digital data sources. This is an important consideration in implementing this type of tool in a regional office or fire operations field setting.

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Modelling Stand Vulnerability to Spruce Budworm Attack: A GIS Approach Using Ecological Variables for a Pilot Mapping Area in Northwestern Ontario.

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Abstract
This paper describes a cooperative project involving forestry Canada and the Ontario Ministry of Natural Resources, in which a GIS approach was used to study a 10km x 10km forest area near Atikokan, northwestern Ontario. The area supports extensive mixed wood stands with a high proportional cover by balsam fir that has been heavily attacked by spruce budworm during the last 10 years. The area was intensively ground surveyed using a forest ecosystem classification and additional data was collected on current tree composition, vegetation and soils. Based on this information and the interpretation of supplementary 1:8 000 photographs, several interpretive map overlays were developed.

A modelling approach, using factors such as present forest composition, stand age, soil moisture regime, soil texture and interpreted balsam fir components in the overstory, was applied to help determine future site and stand vulnerability to budworm attacks. Three models, each using different ecosystem-based information, were developed and applied to the area, and all three showed similar trends. Some implications and advantages of this ecosystem approach to estimating stand vulnerability to spruce budworm are discussed.

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Post-fire Recovery of Riparian Resources on the Idaho Batholith: A Geographic Information System Analysis

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Abstract
The ability of streams to support resident fish populations is largely determined by the character of the aquatic habitat and its interactions with the riparian terrestrial corridor. Major wildfires on the Boise National Forest in southwestern Idaho are expected to change both riparian conditions and fish habitat in forested watersheds. The magnitude of effects and their duration will depend upon the fire severity, the dimensions and sensitivity of affected watersheds, the recovery rate of vegetation, and climatic factors such as storm intensity, frequency and timing. Watershed features and attributes were derived from digital elevation models and field surveys. Spatial coordinates were encoded and plotted to construct thematic and composite maps of burn intensity classes, stream management zones, post-fire erosion hazard, and conifer density adjacent to streams. Geographic information system (GIS) analyses generated resource information for identifying and quantifying erosion-sensitive slopes, streambanks lacking vegetative cover, and conifer stands as a source of woody debris for sediment storage and fish habitat enhancement. This information was useful in planning site-specific recovery projects, mitigation measures, and monitoring programs to determine the effectiveness of recovery efforts in restoring resource values.

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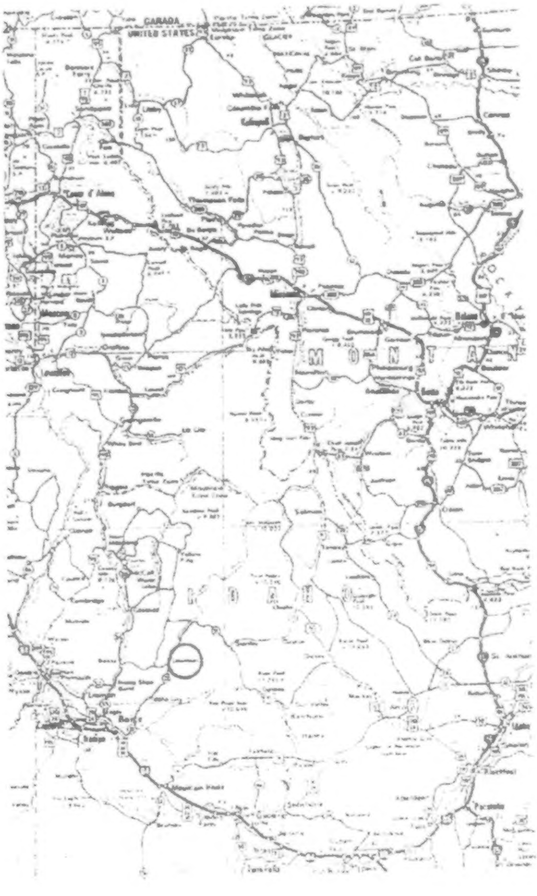
Introduction

Vegetation and soil characteristics strongly influence rates of infiltration, slope and streambank stability, and sediment transport to streams and rivers During the summer of 1989, electrical storms ignited major wildfires in the Salmon River Mountains on the Idaho batholith of southwestern Idaho. Fire-induced loss of streamside vegetation and changes in soil properties reduced water-holding capacity of erosion-sensitive watersheds. The fires also changed the distribution of large organic debris (downed tree boles) in low order headland streams. Accordingly, increased overland water flow rates, accelerated soil erosion and sedimentation are anticipated on sites experiencing high burn intensity. These disturbances can be expected to reduce sediment storage capacity of riparian corridors, alter stream channel stability, and diminish the quality of resident fish habitat.

Geographic information systems (GIS), a computer-assisted technology for capturing, compiling, retrieving, and displaying spatially distributed information, facilitates analysis of environmental impacts resulting from catastrophic events and development of recovery plans (Mead 1990). In response to major wildfires on public lands, resource specialists are assembled to evaluate post-fire conditions and assess the environmental consequences of alternative management activities (Christensen et al. 1989). However, few, if any, published accounts describe the role of GIS in analyzing the effects of wildfires on stream ecosystems (Minshall et al. 1989). This paper reports a GIS analysis of post-fire riparian resources in forested watersheds on the Lowman Ranger District of Boise National Forest. It explores the effects of wildfire on the interaction between streams and the adjacent terrestrial corridor. The paper also documents the contribution of GIS as an analytical tool in fire-recovery studies.



Study Area

The Lowman Complex fire recovery area is located approximately 80 miles northeast of Boise, Idaho, mostly within the Lowman Ranger District administered by the Boise National Forest (Fig. 1a). This wildfire was one the most intense of the devastating 1989 fire season in Idaho. Over 46 000 acres were burned. The fire denuded mountainsides along the South Fork of the Payette River and its tributaries (Fig. 1b).

Watersheds in this area are characterized by steep slopes and highly erodible soils derived from the Idaho batholith, a granitic intrusion. Major beneficial uses of this water resource include habitat for resident fish and wildlife, potable water for domestic use, and recreational opportunities for river rafting and kayaking. The impact of sedimentation on fish habitat quality has been identified as the most important water quality issue affecting forest management in Idaho (Bauer 1987).

Vegetation adjacent to streams varies with topography and landtype. Within the Lowman fire recovery area, elevations range from 4000 to 7700 feet. At lower elevations, riparian communities are dominated by alders, poplars, willows and

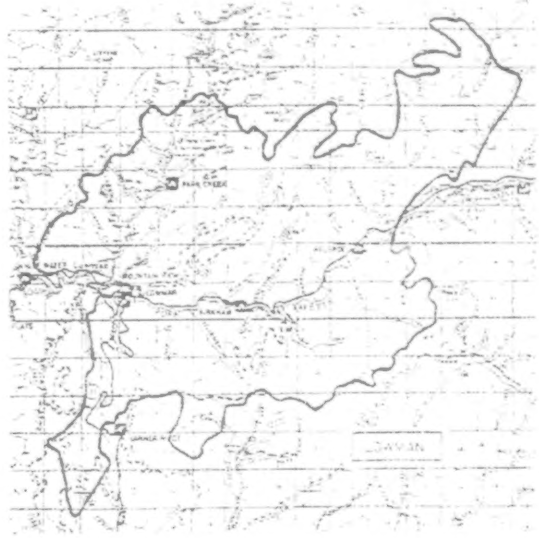


Figure 1a and 1b. Location map and boundary of Lowman Fire Recovery Area , Lowman Ranger District, Boise National Forest, Southwestern Idaho.

sedges; Douglas fir and ponderosa pine are the major overstory conifer series. On terraces along the South Fork Payette River and its tributaries, brush communities include bitterbrush, fescue and ninebark. At mid- to high elevations, subalpine fir and elk sedge occupy wetter sites.

Methods

This study addresses the following resource questions: How to minimize post-fire erosion hazards, protect riparian resource values, and support recruitment of large organic debris to restore fish habitat quality?

As a first step in the analytical process, a multidisciplinary field survey team collected data on burned areas in the Lowman complex and defined fire boundaries on topographic maps. The USDA Forest Service's, Geometronics Service Center, Salt Lake City, provided a digital elevation model (DEM) of the fire analysis area. Data on aspect, slope classes and stream orders were derived from the DEM by line digitizing. Spatial coordinates of mapped features were encoded manually.

A field team also surveyed post-fire vegetation and compiled data on conifer stands, primarily Douglas fir and ponderosa pine. These data were stratified into four density classes and expressed as trees per acre (TPA).

To show the variability of fire damage to vegetation and soils within the fire recovery area, (Fig. 2), burn intensity data was partitioned into four classes defined as follows:

- High Burn: Consumed the soil organic layer and altered mineral structure and color,
- Moderate Burn: Consumed 40-80 percent of the plant canopy, but the soil was not visibly altered,
- Low Burn: Litter and duff were scorched, but not altered over the entire depth,
- No Burn.

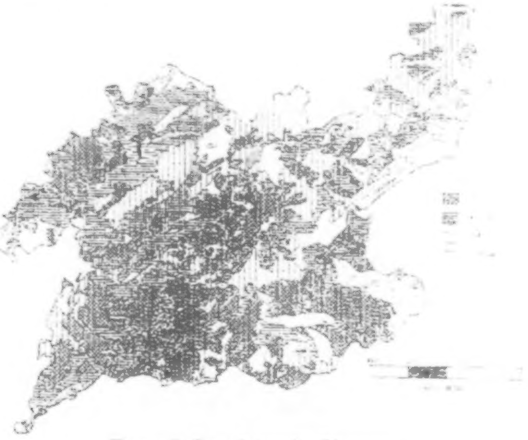


Figure 2. Burn Intensity Classes, Lowman Fire Recovery Area.

Using ARC/INFO, a GIS software program (ESRI 1985), encoded data on burn intensity, conifer density, slope classes, and streams were plotted to produce baseline maps at a scale of 1:24 000. Thematic elements representing slope and burn-intensity class were assembled to estimate post-fire erosion hazard using the following criteria:

Post-fire Erosion Hazard

Element:	None to Low	Moderate	High	Very High
Slope: (percent)	0-20	21-40	41-60	61+
Burn Intensity: Class	Low	Moderate	Mod-High	High

Buffers were created along Class I and II streams to designate riparian management zones (Fig. 3.). Stream classes were defined by beneficial use of the water resource. Class I streams are a direct source of water for domestic use. They provide habitat for large numbers of fish for spawning, rearing or migration. Class II streams are regionally important as a sport fishery.

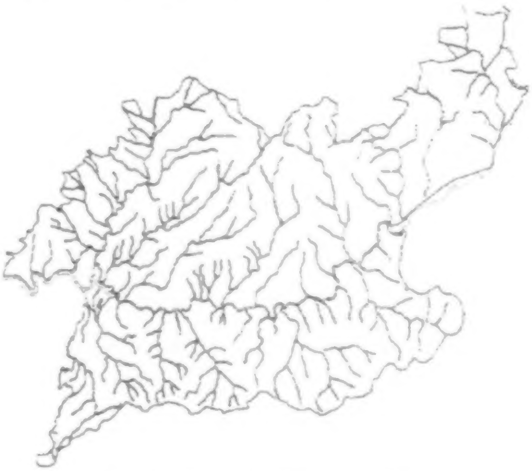


Figure 3. Stream Management Zones, Lowman Fire Recovery Area.

Data on burn intensity were tabulated by stream class (Table I). To locate areas where riparian vegetation and soils experienced a range of burn intensities, these data were merged to produce a composite map displaying burn intensity classes adjacent to stream management zones (Fig. 4). Similarly, data on post-fire conifer density classes was superimposed upon riparian zones to estimate proximity of woody debris to stream channels (Fig. 5).

Results and Discussion

The purposes of this study were to examine the effects of fire on the stream system and the adjacent riparian corridor, and to evaluate the utility of GIS as an analytical tool in fire recovery applications. Results of assessing environmental consequences of alternative management activities in the Lowman fire recovery area will be reported elsewhere (USDA Forest Service 1990).

Class	Intensity	Acres	Percent
I	high	90	36
	moderate	57	22
	low	49	20
	total burned	196	78
	unburned	54	22
total	fire area	250	100
II	high	630	21
	moderate	872	29
	low	1 235	41
	total burned	2,737	91
	unburned	282	9
total	fire area	3,019	100
TOTAL Class I and II Acres Burned:		2,933	
TOTAL Class I and II Acres in Fire Area:		3,269	

Table 1. Burn Intensity in Class I and II Stream Management Zones.

Three related resource issues were identified: to minimize the potential for post-fire erosion and accelerated sedimentation; to stabilize channel morphology and protect streams from sediment input; and to restore fish habitat quality by insuring adequate supplies of large woody debris.

In drainages characterized by steep erosion-sensitive slopes, high intensity fires that destroy plant cover and reduce water-holding capacity of soils will increase the potential for runoff and sediment transport to nearby streams. GIS-generated maps of post-fire erosion hazard helped to identify sites of potential downstream flooding and to locate stream segments where increased sediment yields are expected.

Accumulation of fine sediments in spawning and wintering habitat, and changes in stream structure that reduce pool depth, contribute to degradation of fish habitat quality. Comparison of streamside areas burned in Class I and Class II stream management zones (Table 1) provides evidence that the greatest impact of the fires are most likely to be observed in smaller headwater streams. These results are consistent with other observations on fire effects and stream size (Minshall et al. 1989).

Riparian vegetation is a critical factor in determining streambank stability and fish habitat quality (Mahoney and Erman 1984). Roots of streamside grasses, sedges and shrubs stabilize soil and reduce streambank erosion. Vegetation within the stream management zone also serves a sediment storage function to intercept and impede the flow of eroded material into the stream channel. Along low-order headwater streams, riparian vegetation provides a canopy to shade streams during summer low-flow periods (Amaranthus et al. 1989). In addition, leaf litter derived from streamside vegetation is an important source of allochthonous organic matter for aquatic macroinvertebrates that serve as food for resident fish populations (Kaushik and Hynes 1971).

By comparing GIS maps and tables showing distribution of burn intensity classes by stream management zone, areas deficient in riparian vegetation were identified. Information derived from GIS-assisted analysis called attention to the need for rapid restoration of vegetative cover.

In forested watersheds, riparian vegetation is the primary source of woody debris for enhancing fish habitat quality. When stabilized within stream channels, coarse woody debris traps sediment and contributes to habitat diversity by creating waterfalls and pools (Bilby 1988). GIS analysis of conifer stand densities along stream courses identified riparian areas deficient in woody debris (Hemstrom 1989), and provided information for potential recruitment of large woody material from adjacent sources.

The quantity of large woody debris will increase as fire-killed snags within the riparian corridor fall into the stream channel. Roughly half of the snags are expected to fall in the first decade after the fire, the remainder within the next two decades.

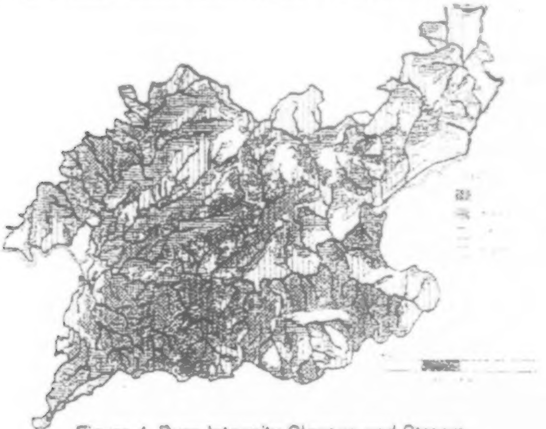


Figure 4. Burn Intensity Classes and Stream Management Zones, Lowman Fire Recovery Area.

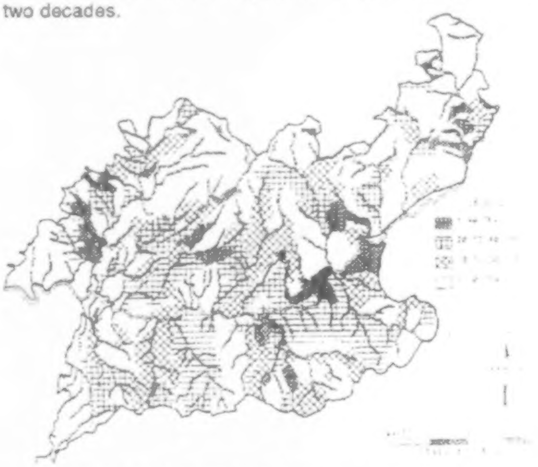


Figure 5. Conifer Density Classes adjacent to Stream Management Zones, Lowman Fire Recovery Area.

Results of these analyses provide information for planning post-fire recovery projects, mitigation measures to minimize impacts of forest management activities, and for monitoring rehabilitation efforts. Based on early review of burn intensity patterns within the recovery area, emergency rehabilitation measures were implemented immediately after the fire to stabilize soils and re-establish vegetation. These efforts included cross-felling and stabilizing log structures perpendicular to the slope, seeding with a mixture of grasses, and treating severely burned slopes with a biodegradable soil stabilizer (Fig. 6). Log structures were also installed in small streams to trap sediment. Recovery plans call for reforestation, shrub planting and long-term monitoring of the recovery process.

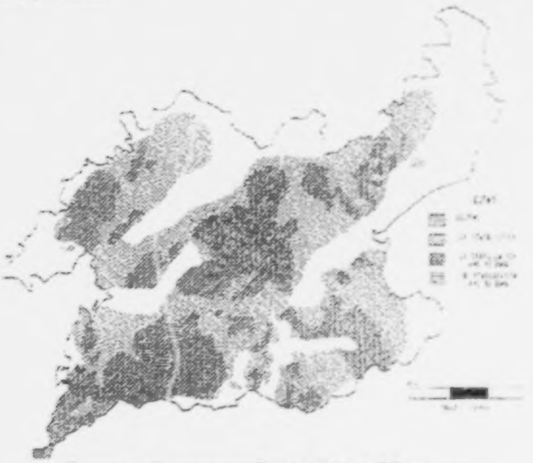


Figure 6. Emergency Rehabilitation Measures, Lowman Fire Recovery Area.

Summary and Conclusions

To assess the impact of large-scale catastrophic disturbances, GIS-technology provides resource specialists with analytical opportunities to tabulate resource data, generate thematic and composite maps, compare pre- and post-event conditions, and access information on resource distribution patterns (Ottawa 1989). In responding to issues and concerns posed by the Lowman fire complex, statistical and spatial information derived from reports and maps produced by GIS markedly enhanced analysis of erosion-sensitive drainages in the South Fork Payette River watershed. Computer-assisted technology provided simple and efficient methods for:

1. Identifying drainages subject to potential downstream flooding,
2. Locating streambanks exposed to varying levels of burn intensity,
3. Displaying the distribution of stream segments deficient in riparian vegetation,
4. Calculating areas within unprotected riparian zones vulnerable to increased sediment yield,
5. Determining proximity and access to conifer stands as a source of contour-log structures for erosion control on steep slopes,
6. Estimating the quantity of large woody debris available for in-stream log structures to enhance fish habitat quality,
7. Predicting stream orders where the greatest impact of the fires are likely to be observed; and
8. Planning post-fire recovery activities to restore riparian resource values within the watershed.

GIS analyses strongly support multidisciplinary efforts to recover wildfire-damaged resources, guide the development of management alternatives, and set priorities for implementing rehabilitation measures and other riparian restoration activities. GIS technology displays the resource information in a form that facilitates interpretation, communication and encouraged public participation in the process.

Acknowledgements

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Managing Resource Conflict

Session B2
GIS for Wildlife and Habitat Management - 1

Dynamic Habitat Evaluation Within a GIS Framework

Remote Sensing and GIS Technologies: An Example of Integration in the Analysis of Cougar Habitat Utilization in Southwest Oregon

Integrated Management of Forestry and Wildlife Habitat with the Aid of a GIS-based Habitat Assessment and Planning Tool

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Dynamic Habitat Evaluation Within a GIS Framework

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Abstract
A microcomputer-based habitat evaluation program has recently been linked with a GIS to provide for a more dynamic evaluation of proposed habitat alterations. The habitat evaluation program (GDI/HEP) is based on a modified version of the U.S. Fish & Wildlife Service's Habitat Evaluation Procedures (HEP). A software interface was developed to link GDI/HEP and PC ARC/INFO, a widely used PC-based GIS package. Via this linkage, it is possible to transfer compartment numbers, habitat cover types, and acreage values from digitized maps to GDI/HEP and vice versa. This interactive tool affords resource managers the ability to develop "what if" scenarios, and to graphically display changes in habitat suitability due to habitat alterations. To demonstrate the utility of this combined approach, a pilot study was conducted on a 19 000 acre site in central Pennsylvania. For this site, various construction and mitigation alternatives were evaluated by comparing the relative change in habitat units.

Introduction

Large engineering projects often require environmental analyses and production of environmental impact statements (EIS). One portion of such an analysis is the assessment of impacts on wildlife habitat. This requires wildlife censuses and studies which project the post-construction conditions onto the wildlife habitat. Since these types of projects can be difficult and expensive, increased attention has been focused on modeling wildlife habitat conditions as an additional and potentially lower-cost source of data for environmental analysis.

Recent studies (e.g., Mead, et al., 1981; Lyon, et al., 1987; and Hodgson, et al., 1988) have demonstrated the utility and cost-effectiveness of evaluating habitat with a geographic information system (GIS). However, these and similar studies have centered on the use of specialized GIS software and/or non-standard habitat models, both of which present implementation difficulties to government agencies striving for consistency within regional or state-wide jurisdictions. This paper describes the linkage between a widely-accepted habitat evaluation method and a widely-used GIS.

Habitat Model and GIS Linkage

Natural resource managers in Pennsylvania first considered incorporating habitat evaluation into impact assessments and management plans in the early 1980's. The evaluation method adopted initially within the state was the Habitat Evaluation Procedure (HEP) developed by the U.S. Fish & Wildlife Service (1980). With HEP, habitat evaluation is based on vegetative or land cover types. The quality of each cover type is numerically characterized by the degree to which it provides the life requisites of an indicator species. The overall habitat suitability for a given area is a function of habitat suitability index (HSI) scores for various indicator species, and "habitat units". Habitat units equal HSI scores multiplied by the respective acreages evaluated for each guild species.

In Pennsylvania, the standard HEP process was judged to be too time-consuming and expensive for a vast majority of projects conducted within the state, which tended to be of a smaller scope. Because they felt that thousands of smaller projects could benefit from habitat evaluation, wildlife professionals in Pennsylvania cooperatively developed a shortened version of USFWS 1980 HEP called Pennsylvania Modified Habitat Evaluation Procedure (PAM HEP). This condensed version still maintains the strengths of USFWS 1980 HEP, including the species models, but reduces the paperwork to 15 forms.

Even with PAM HEP, however, the task of filling out forms still remained a tedious process requiring hundreds of calculations. In order to assist those individuals using PAM HEP, Geo Decisions, Inc. (GDI) developed GDI/HEP, a full-screen, user-friendly software package designed specifically for PAM HEP. With GDI/HEP, the user keypunches in limited information for only 7 forms - the other 8 are produced automatically. GDI/HEP has a built-in library containing species models for over 50 birds, mammals, amphibians and fish (which can be edited and added to), and provides the ability to print out all computer-generated and user-generated forms. Although PAM HEP and GDI/HEP are used primarily in the northeast portion of the country, their flexibility enables them to be used anywhere in the United States.

To take advantage of the power and versatility offered by existing GIS technology, software interfaces are being developed to provide a link between GDI/HEP and several widely-used GIS packages. The first such linkage was developed for PC ARC/INFO, a vector-based system created by Environmental Systems Research Institute in Redlands, California. Via this linkage, it is now possible to transfer compartment numbers (i.e., unique polygon identification numbers), habitat cover types, and acreage tabulations from digitized maps to GDI/HEP and vice versa. As described in greater detail below, this interactive tool affords resource managers the ability to develop "what if" scenarios and to graphically display changes in habitat suitability due to habitat alterations.

Pilot Study Results

To demonstrate the utility of the combined GIS/habitat evaluation approach, a pilot study was conducted using data compiled for the Letterkenny Army Depot in southcentral Pennsylvania. For this 19 000-acre site, various construction and mitigation alternatives were evaluated by comparing the relative change in habitat units.

Figure 1 depicts the land cover type polygons delineated for the study area. This map was prepared via the interpretation of available low-altitude color infrared aerial photographs, and subsequent digitizing with a Calcomp line digitizer. As the land use/cover map was being produced, field data was collected for the purpose of assigning HSI scores to representative land cover polygons (i.e., compartments). With the GIS interface, it was possible to prepare a habitat suitability map for a variety of guilded species. One such map produced for cottontail rabbits is shown in Figure 2. In this map, shaded areas indicate where HSI scores were greater than 0.5.

Using the GDI/HEP-ARC/INFO link, several habitat management alternatives for critical wildlife species were quickly evaluated. Figure 3 depicts the suitability map created for one of the habitat management alternatives for cottontail rabbits.In this instance, an estimated net gain of approximately 1219 habitat units would be achieved by implementing this particular management alternative, which involved timber harvesting. As with the previous map, only areas having HSI scores greater than 0.5 were shaded.

Similarly, habitat suitability maps were also created for several construction alternatives. Again, in the case of cottontail rabbits, it was demonstrated that one construction alternative would result in about 45% less net loss in habitat units due to construction activities than another construction alternative under consideration (see Figures 4 and 5). These latter two examples reflect the more traditional use of HEP; that is, as a tool for developing and selecting construction and mitigation alternatives based on the loss of Habitat Units (HUs).

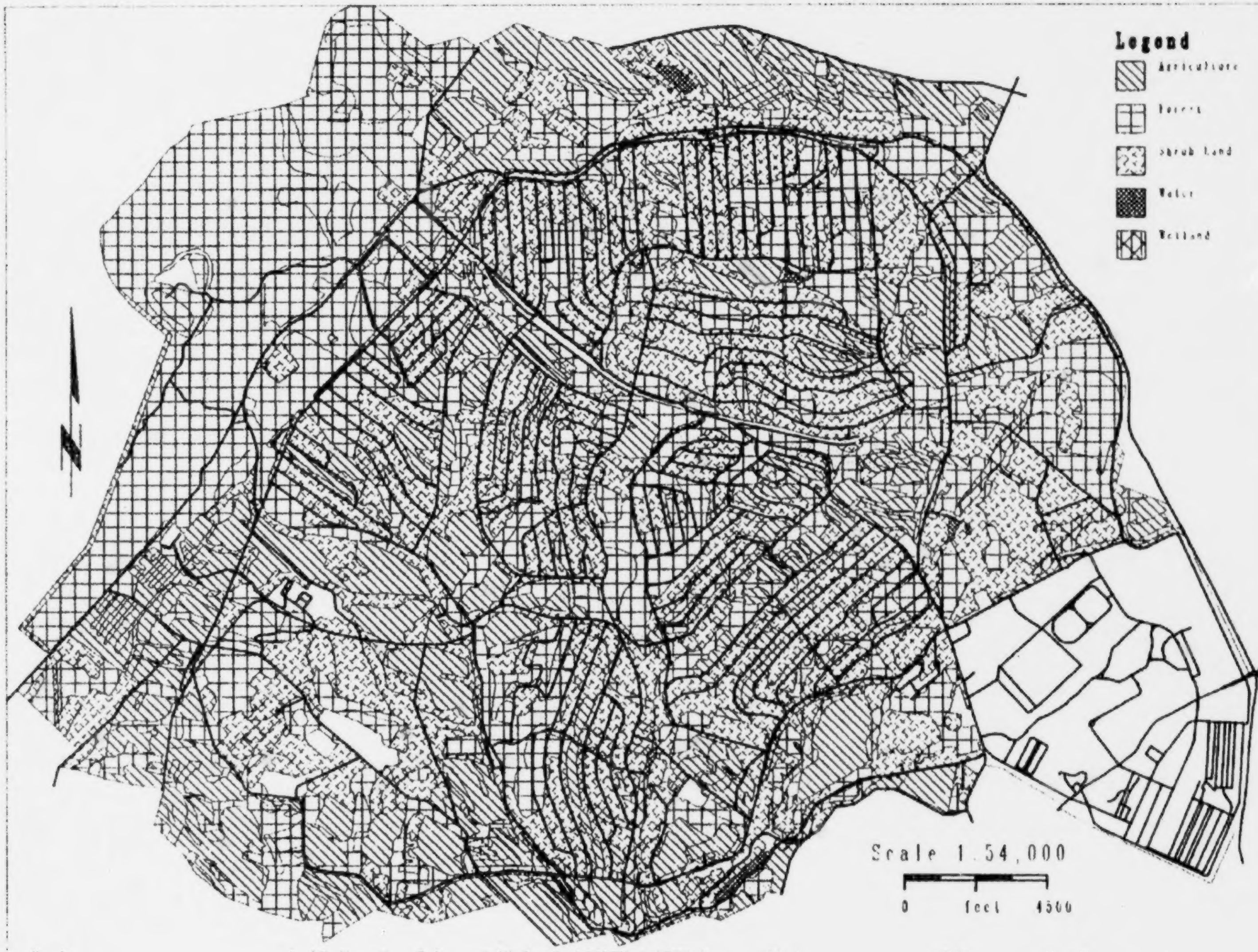
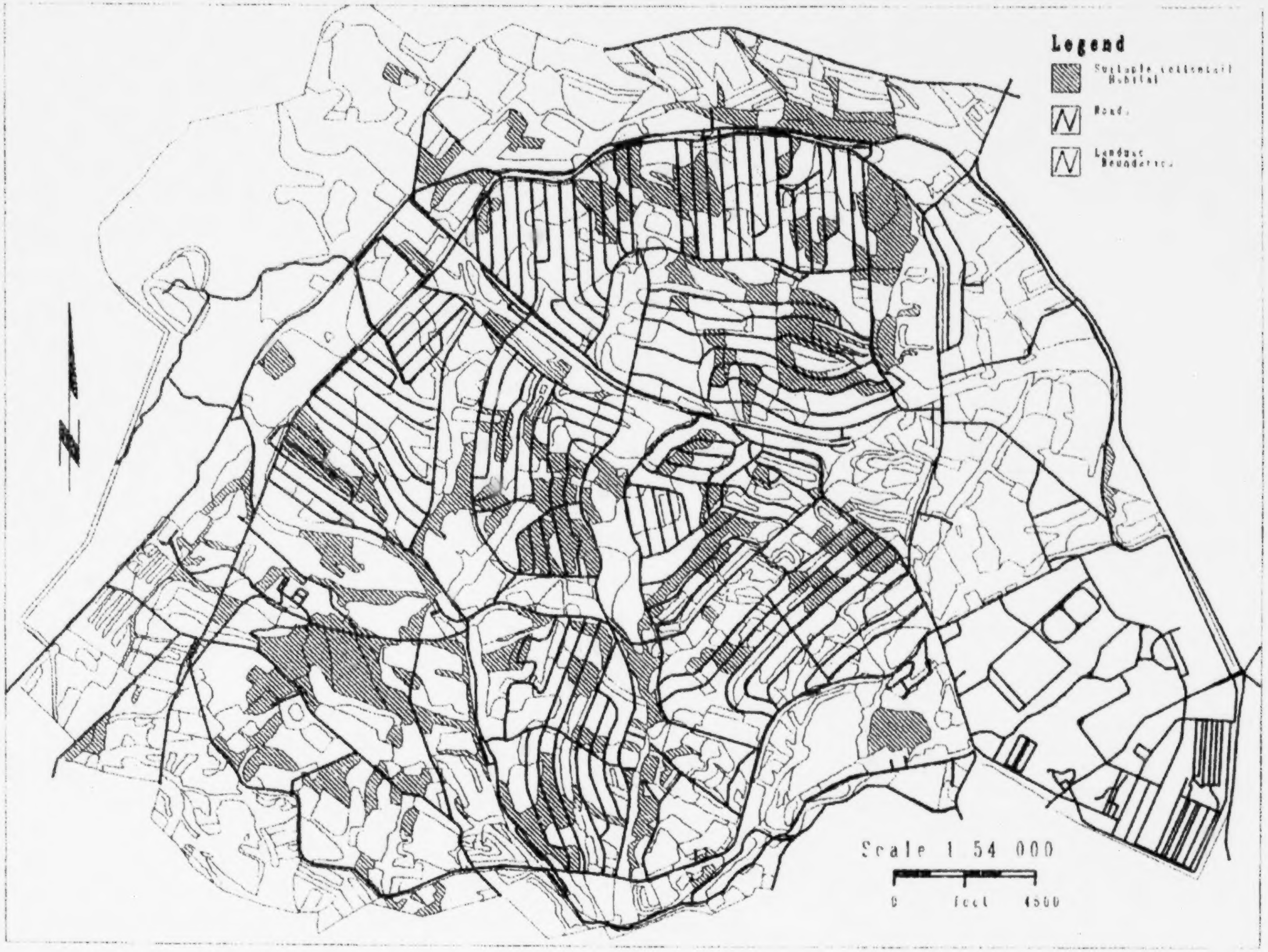

Legend
Agriculture
Forest
Shrub Land
Water
Wetland
Scale 1:54,000
0
feet
4500

Figure 1. Generalized land use/cover map of study site



Legend
Suitable cottontail Habitat
Roads
Landuse Boundaries
Scale 1 54 000
0
feet
4500

Figure 2. Baseline habitat suitability map for cottontail rabbit.

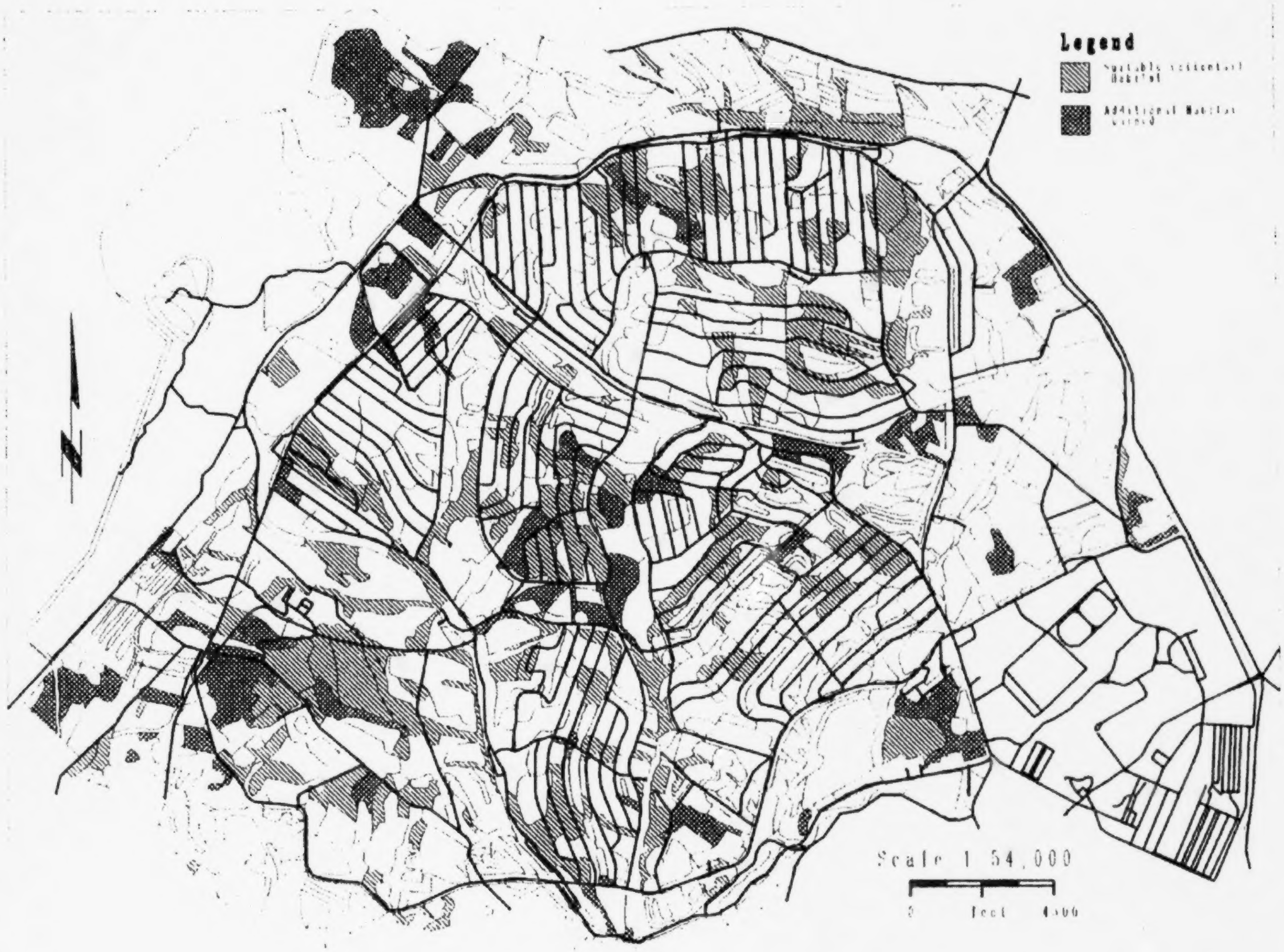

Legend
Suitable cottontail Habitat
Additional Habitat Gained
Scale 1 54,000
0
feet
4000

Figure 3. Predicted habitat suitability map for cottontail rabbit based on implementation of one of several management alternatives.

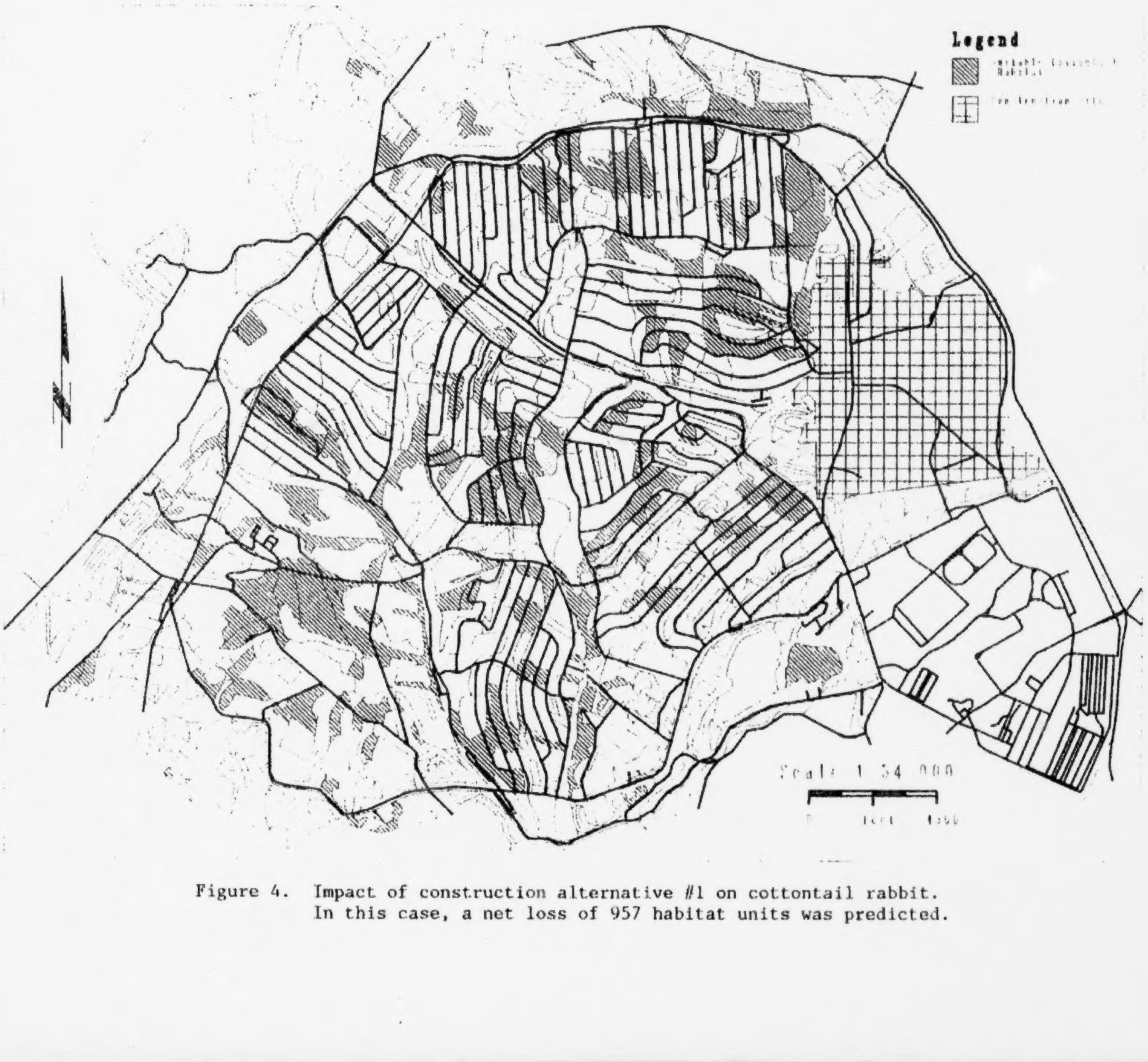

Legend
Habitat
Scale 1:24 000
0
feet
4000

Figure 4. Impact of construction alternative #1 on cottontail rabbit. In this case, a net loss of 957 habitat units was predicted.

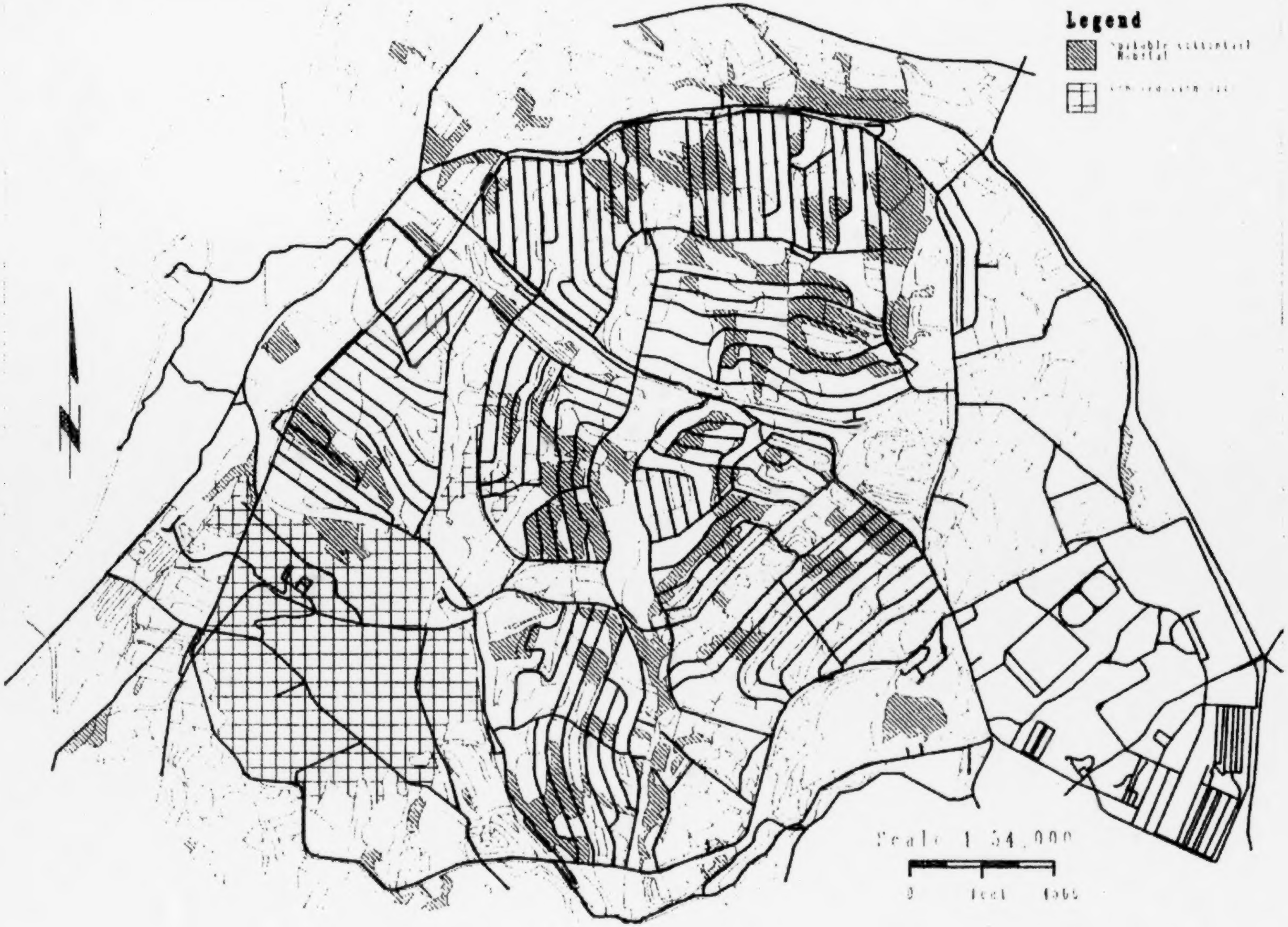

Legend
Suitable cottontail Habitat
Scale 1:54,000
0
feet
4000

Figure 5. Impact of construction alternative #2 on cottontail rabbit. In this case, a net loss of 1737 habitat units was predicted.

Concluding Remarks

The GIS interface as described also allows users of GDI/HEP to "weight" HSI scores based on the juxtaposition of habitat types and the perimeter/acreage ratio of evaluated compartments. Heinen and Lyon (1989) suggest that such factors will become increasingly more important as the use of GIS becomes more prevalent in wildlife habitat evaluation. For example, HSI scores for edge species such as white-tailed deer would increase slightly with a "high degree" of juxtaposition and edge diversity. The opposite would be true for interior species such as the red-eyed vireo. In either case, weighted HSI scores would more accurately reflect environmental conditions.

As illustrated in this paper, GIS systems provide the capability to accurately portray baseline, construction and mitigation alternatives for habitat evaluation studies. They also provide the added ability to attach attributes to each compartment or polygon. Polygon attributes such as HSI scores, slope, aspect, and other types of geo-referenced data can be used to produce maps and related quantitative data necessary to achieve the goals of a particular habitat study.

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Remote Sensing and GIS Technologies: An Example of Integration in the Analysis of Cougar Habitat Utilization in Southwest Oregon

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Abstract
The impacts of human activities and habitat alterations on cougar (*Felis concolor*) habitat use were studied in southwest Oregon through the application of remote sensing and GIS technologies. Habitat selection, movements, and home range of eight radio-collared cougars were determined during 1986 and 1987. Map layers required for analysis included forest stand conditions, riparian zones, forest road systems, forest management activities, watershed boundaries, permanent residences, campgrounds, land ownership patterns, and radio-telemetry locations. Habitat classifications were accomplished using SPOT satellite imagery. NHAP infra-red aerial photography were used to verify forest stand conditions. Data for other map layers were obtained through US Geological Survey topographic maps, US Forest Service, Bureau of Land Management, and Oregon Department of Forest Protection planimetric maps and information files. Data for all layers were digitized and converted to raster format for input and analysis with the Oregon Department of Fish and Wildlife's EPPL7 geographic information system. GIS applications included closest distance and neighbor analyses. Chi-squared and mean tests were performed on cougar telemetry data in relation to human disturbances and forest stand conditions. Movement patterns of cougars were described using digital terrain models developed from aerial photography by an analytical stereo plotter. Continuous movements of cougar were incorporated into the three-dimensional habitat models, and were described relative to human perturbations and habitat structures.

Introduction

The previous three decades have produced technology advancements which have allowed wildlife researchers to address questions never before examined. The advent of radio-telemetry provided the technology necessary to research many undocumented aspects of wildlife populations (Mech 1983). More recently, geographic information systems and remote sensing have increased the power and scale of spatial analyses (Ehlers et al 1989; Berry 1981). Combined with radio telemetry data, these technologies offer powerful methods of data manipulation and analysis (Koel and Cook 1984). Additionally, these technologies are becoming increasing available in PC environments. The purpose of this paper is to present an example of the integration and application of these technologies in a PC environment for the analysis of radio-telemetry data. Specifically, the methodology utilized in research concerned with the impacts of human activities on cougar habitat use in southwest Oregon is discussed.

Study Area

The study area, located on the west side of the Cascade Range in southwest Oregon, comprised 2250 square kilometers in the upper reaches of the North Umpqua River drainage (Figure 1). Habitats are dominated by subclimax Douglas Fir (*Pseudostuga menziesii*), intermixed with western red cedar (*Thuja plicata*) and hemlock (*Tsuga heterophylla*) (Franklin and Dyrness 1973). Elevations increase in a west-to-east direction through the study area, and range from 500 to 2000 meters.

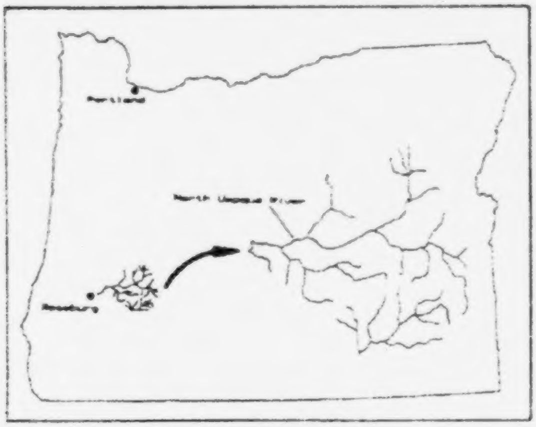

Figure 1. Study area location:
North Umpqua River Drainage

Methods

Cougars were captured and immobilized with the aid of local houndsmen. Immobilized animals were immediately examined and fitted with a radio collar manufactured by Telonics, Inc., following the guidelines outlined in Seidensticker et al (1970).

Telemetry data were collected as independent and sequential locations. Independent data were collected on a randomized schedule, with locations obtained from the ground and the air. A period of one to three days between locations was maintained to ensure independence of data points. Sequential locations were collected from the ground, and were spaced over a period of 24 to 36 hours. A minimum of 2 continuous monitoring periods were collected for each animal.

The study area was divided into 80 square 5000 meter Universal Transverse Mercator (UTM) coordinate system blocks (Figure 2). Independent and sequential locations were plotted on 1:24 000 USGS topographic maps and converted to UTM coordinates through the use of digitizer pads and supporting software. Aerial locations (latitude, longitude) were converted to UTM coordinates with the use of conversion software. All actual locations were entered into a PC, and coded to indicate type, study animal, date, and time of day. Vector format files of locations were converted for input and analysis within EPPL7, a raster-based geographic information system provided by the Oregon Department of Fish and Wildlife.

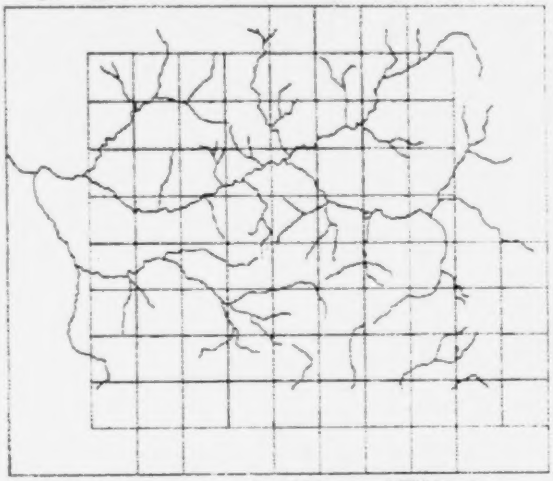

Figure 2. Study area with 5000 meter UTM blocks

Home range analysis was performed only on data collected from resident adults. Juxtapositions of animal home ranges were described by mapping home ranges using the UTM coordinate system at various, but matching scales. Displacement of juvenile and transient cougars was documented by individual aerial telemetry locations, and plotted using the UTM coordinate system.

Random UTM pairs for analysis were generated by a FORTRAN program (unpublished data). Independent and random data points were classed by stand age, topographic relief (elevation and aspect), and distance to riparian zones. Habitat classifications were based on five of the categories presented in Brown et al (1985) (clearcut, shrub/forb, open pole, closed pole, mature) and were accomplished through interpretation of satellite imagery. Three-band composite (red, green, and near infra-red) 1:100 000 scale photography of the study area was acquired for July, 1986 from Spot Image Corporation. A UTM grid for the satellite photographs, developed from 1:100 000 scale BLM planimetric maps, was scribed onto the imagery using ground control features. Overlays of randomly located and actual telemetry locations were produced on 1 millimeter vellum grids for each 5000 meter block at the appropriate scale. Classification of the data point was confirmed using NHAP 1:60 000 infra-red aerial photography. Proportions of random and actual data points were developed for each habitat category by individual animal, as averages by sex, and as overall averages.

Statistical analysis of habitat utilization was conducted following the procedures outlined by Marcum and Loftsgaarden (1980). Random and observed locations were tested for cougar habitat utilization relative to availability. A Chi-squared analysis was performed to test the null hypothesis that cougar use of each habitat category was in proportion to its occurrence within the study area (Figure 3).

Habitat Utilization Analysis
↓
Plot UTM Coordinates on Multispectral Photos
↓
Classify
↓
Verify Classification with Infra-red High Elevation Photos
↓
Repeat for Random Locations
↓
Test Habitat Utilization by Calss with Availability
(Chi-Square/Means Analysis)

Figure 3. Procedure implemented for habitat analysis

Riparian areas for each UTM block were digitized from 1:24 000 USGS topographic maps, converted from vector to raster format, and input into EPPL7. Separate map layers for riparian zone, actual locations, and random locations were developed for each animal by mosaicking the appropriate blocks (Figure 4). These layers were combined and nearest distance analyses to riparian zones were performed (Figure 5). Averages were calculated, and the analysis previously described was utilized to test for differences between the mean distances to riparian zones of random versus actual locations.

Continuous monitoring periods were utilized to describe movement patterns within each animal's home range. Digital elevation models from 1:31 000 black and white aerial photography were developed using an analytical stereo plotter and displayed using surface modeling software. The UTM coordinates of the periods were incorporated into the models, and described in relation to the spatial pattern of stands with differing age class structures, topographic relief, and riparian zones. Straight line distances for each animal's continuous monitoring period were determined between successive locations, and calculated in terms of distances travelled per unit of time and time of day (day versus night).

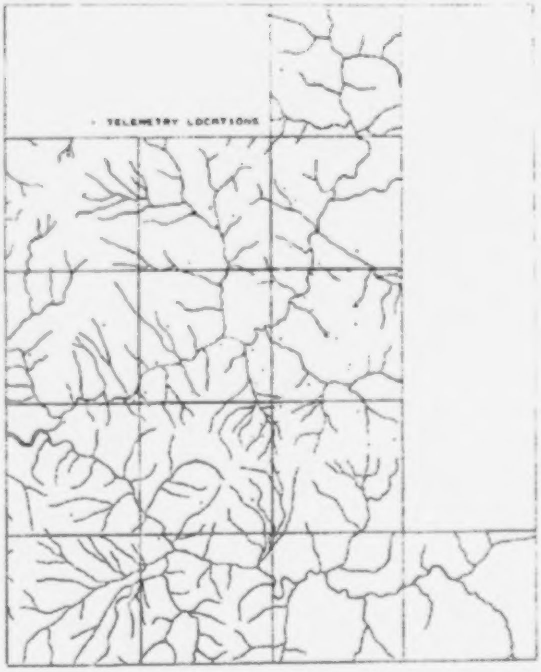

Figure 4. An example of a female cougar's home range with riparian zones overlain with telemetry locations

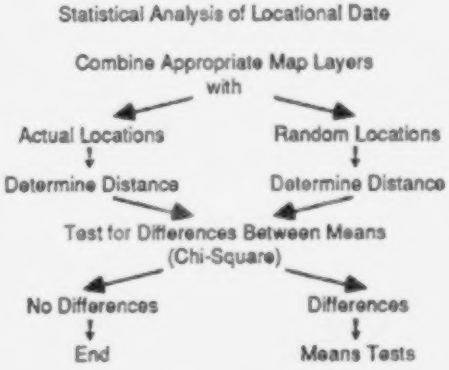

Figure 5. Procedure for distance analysis

Human disturbances were classified as on-going forest management activities, including final harvest, commercial and pre-commercial thinning, and prescribed burning. Location, date, and type of activity were obtained from U.S. Forest Service (USFS) resource inventory files, Bureau of Land Management (BLM) activity records, and Oregon Department of Forest Protection (ODFP) information files. Another primary category of human perturbations examined was the forest road system. This system's impact was investigated in relation to road location, type, and densities, active construction, commercial use, and recreational use. Road systems were classified into 4 road types (four-wheel drive, tertiary, secondary, and primary roads). Other categories of human disturbance included riparian zone campgrounds and permanent residences or ranches.

All categories of human perturbation occurring during 1986 and 1987 were located, typed, plotted on USGS and USFS topographic maps, and digitized relative to their respective UTM blocks (Figure 6). Road systems were digitized from USGS and USFS road maps, and typed according to category. Vector files of all categories were converted to raster format for input into EPPL7.

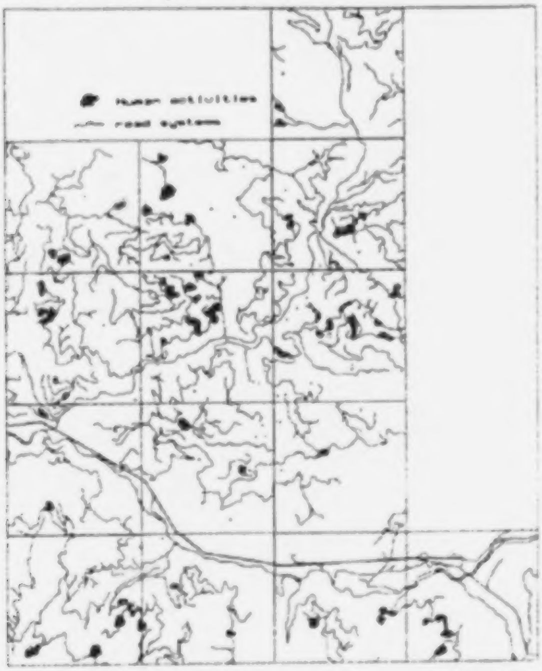
human activities
road system

Figure 6. Human activities, road systems, and telemetry locations of a female cougar's home range during 1986

Independent telemetry and random test location map layers were combined with each map layer of human disturbance for neighbor and distance analysis (Figure 7). Forest management activities were included in nearest distance measures if telemetry locations were within 3000 meters of an activity and the period of activity. Impacts of road systems were analyzed by type of road, with nearest distance measures being performed on all telemetry locations, regardless of distance. The categories of riparian zone campgrounds and permanent residences or ranches were analyzed in the same manner as current forest management activities, with the distance being reduced to 1500 meters. Statistical analysis of independent locations were conducted following the procedures previously outlined. Random and observed locations were tested for indications of utilization and/or avoidance of habitats impacted by human perturbations and forest road systems.

Continuous monitoring periods were conducted during peak levels of human activity (opening days of hunting seasons, ongoing forest management activities, holidays), and during periods when human activities were at or below normal levels (mid-week, forest road closures). The UTM coordinates of the periods were incorporated into the digital elevation models, and described in relation to human perturbations which were presumed to have a direct impact on the habitat use by the study animals. Periods conducted during higher levels of human activities were compared to those conducted during lower levels of activity. Cougar movement patterns were described visually, and compared to determine if cougars actively avoided habitats impacted by these perturbations.

Results

Fifteen cougars were treed; 12 in 1985-86 and 3 in 1986-87. Of these animals, 8 were immobilized and fitted with radio collars, 5 during 1985-86 and 3 during 1986-87. Telemetry locations were collected from 8 radio-collared cougars during the period November, 1985 through January, 1987. Of these 8 animals, 5 were resident adults (2 males, 3

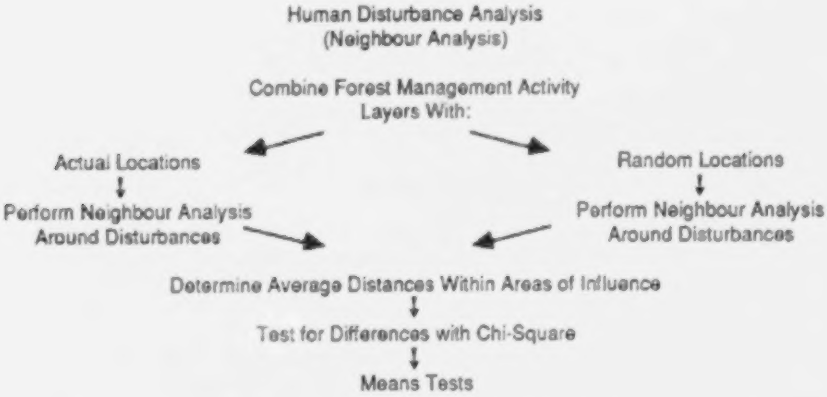
Human Disturbance Analysis
(Neighbour Analysis)
Combine Forest Management Activity
Layers With:
Actual Locations
Random Locations
Perform Neighbour Analysis
Around Disturbances
Perform Neighbour Analysis
Around Disturbances
Determine Average Distances Within Areas of Influence
Test for Differences with Chi-Square
Means Tests

Figure 7. Procedure for human disturbance analysis

females), 2 were transients, (non-resident adults, both female), and 1 was a juvenile (male). Three resident cougars (1 male, 2 female) were collared and monitored during 1985-86, with the remainder of the resident adults (1 male, 1 female) captured and monitored in 1986-87.

Locations were successfully converted from USGS topographic maps to vector format UTM coordinates. Data was also digitized for all other map layers, including riparian zones, forest road systems, human disturbances, and permanent residences/ranches. Root mean square errors for ground control averaged less than 3 meters actual ground distance (unpublished data).

Home range analysis was performed on the UTM coordinates with available software. Juxtaposition of home ranges were examined with plotted data by year of capture, sex, and combined (unpublished data) (Figure 8). Displacement of juveniles was also examined with plots of telemetry locations (unpublished data).

Habitat analysis required the accurate scribing of the UTM grid onto the satellite photography. The availability of a SPOT scene acquired under good conditions (2.3 degrees off vertical, mid-day exposure, July acquisition date, 0 percent cloud cover) allowed for an accurate fit with the BLM 1:100 000 planimetric maps. Root mean square errors for ground control points were less than 7 meters ground distance (unpublished data). Once the grid was established, the overlays of random and actual locations were created, and each point classified. Preliminary results indicated that cougars utilize certain age classes of timber in greater proportion than availability would suggest (unpublished data).

Distance analyses were conducted with the GIS. Individual UTM blocks for each category were converted to raster format, and mosaicked within the GIS by animal home range. Software limitations restricted rasterizing to blocks no larger than 200 rows by 200 columns, which resulted in a pixel size of 25 meters by 25 meters. Distance functions were applied to each map layer, and overlain with the random and actual locational map layers. Mean minimum distances to riparian zones and road systems were determined and tested for differences between the means. Minimum distances within 3000 meters of forest management activities, and 1500 meters of active forest campgrounds and permanent residences were also determined and tested. Preliminary analysis suggests no statistical difference between random and actual distance measures (unpublished data).

Digital elevation models were developed by study animal for each continuous monitoring period. Model parameters were limited to a maximum of 5 meters overall error. Movement patterns were incorporated and examined in relation to age classes, riparian zones, forest road systems, and human disturbances (unpublished data). An example of one monitoring period for a female cougar in relation to the forest road system and human perturbations is shown (Figure 9).

Discussion

One of the primary concerns in the creation of any spatial data base is the minimisation of introduced error (Bailey 1988; Chrisman 1987; Jenks 1981). The greatest source of error in this study was associated with radio telemetry locations, with locational error being approximately 50 meters in any direction (unpublished data). Using the methods described, it was possible to maintain ground control errors for data input well within the accuracy of the telemetry locations. Error associated with the transfer of UTM grid coordinates to the SPOT imagery constituted another area of concern. The conditions under which the scenes were taken and the moderate elevational change in the study area allowed for minimal error additional to the resolution of the scene (unpublished data). A third potential source of error was obtaining spatial data from several different planimetric sources. The ground grid that was established provided adequate bridging control between data sources. An example of this can be seen in Figure 10, which shows the fit between the forest road system (obtained from USGS and USFS maps) overlain with manage-

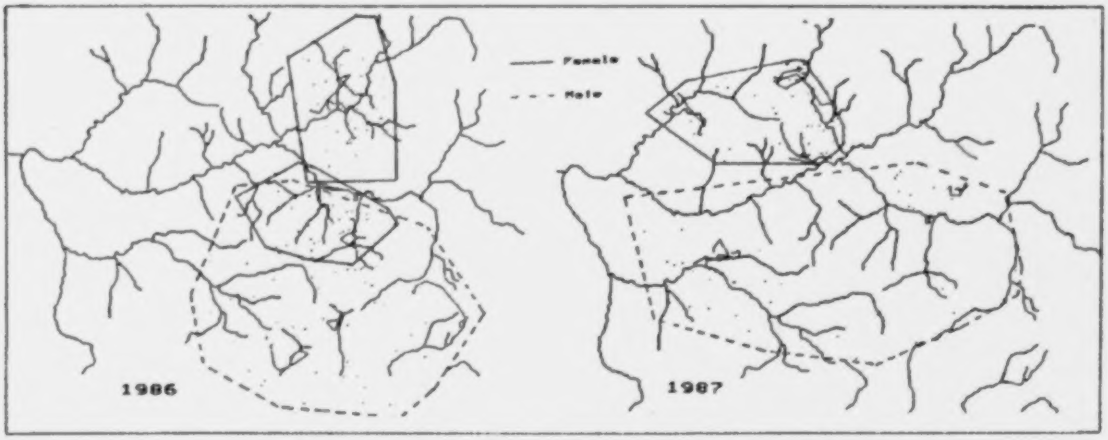

Figure 8. Juxtaposition of home ranges for 1986 and 1987 study animals

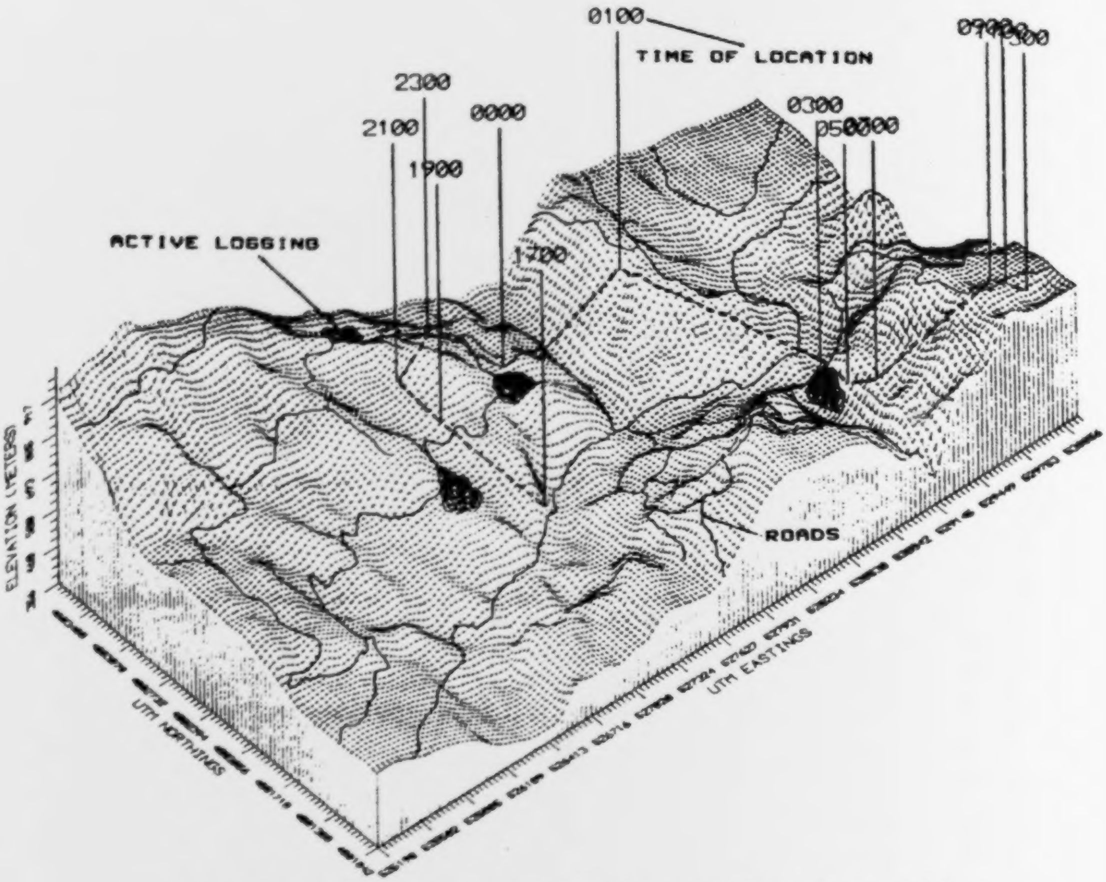

Figure 9. An example of continuous telemetry date incorporated into an elevation model showing road systems and human disturbances

ment units (obtained from SPOT photography). Digitizer error was minimized through extensive practice prior to data entry (Otawa 1987). Tests of digitizing accuracy indicated an average of less than 5 percent deviation from actual coordinates, lengths, and areas (unpublished data). The ground control grid also afforded some control of digitizing error. A FORTRAN program was written which truncated any data outside its respective UTM block, and utilized the boundary as parameters to check the UTM vector coordinates.

The statistical analysis of habitat use presented by Marcum and Loftsgaarden (1980) provided a quick and accurate method to test habitat utilization without requiring a map base. Classifying data points directly from the satellite photography eliminated digitizing error, which can be substantial at smaller scales. The stratification into UTM blocks afforded flexibility in the manipulation of habitat data. For example, how the percentages of different habitat types changed through the study area could easily be graphed. It also provided for quick combination and/or exclusion of UTM blocks for each animals analysis.

The primary GIS function in this research was distance measures relative to habitat characteristics and human disturbances. Pixel cell size is a critical consideration when performing distance analysis (Wehde et al 1981). The resultant pixel size from the 5000 meter blocks was deemed acceptable small, especially when the zone of influence of each category and telemetry error were considered. Because raster files were derived from vector files corrected to their UTM boundaries, the fit between raster blocks was exact. No forced alignment of features between blocks was required, and a function within the GIS allowed for UTM coordinates to be assigned to row-column positions, thereby maintaining ground reference.

The creation of digital elevation models using an analytical stereo-plotter provided a highly accurate and visual method of examining movement patterns. The ground accuracy of the plotter, a Carto AP190, has been shown to be within 10 feet using 1:31 000 black and white photography (unpublished data). The display of sequential data points in three-dimensional terrain aided in visualizing the movement patterns of cougars, especially in relation to habitat components and human disturbances (unpublished data).

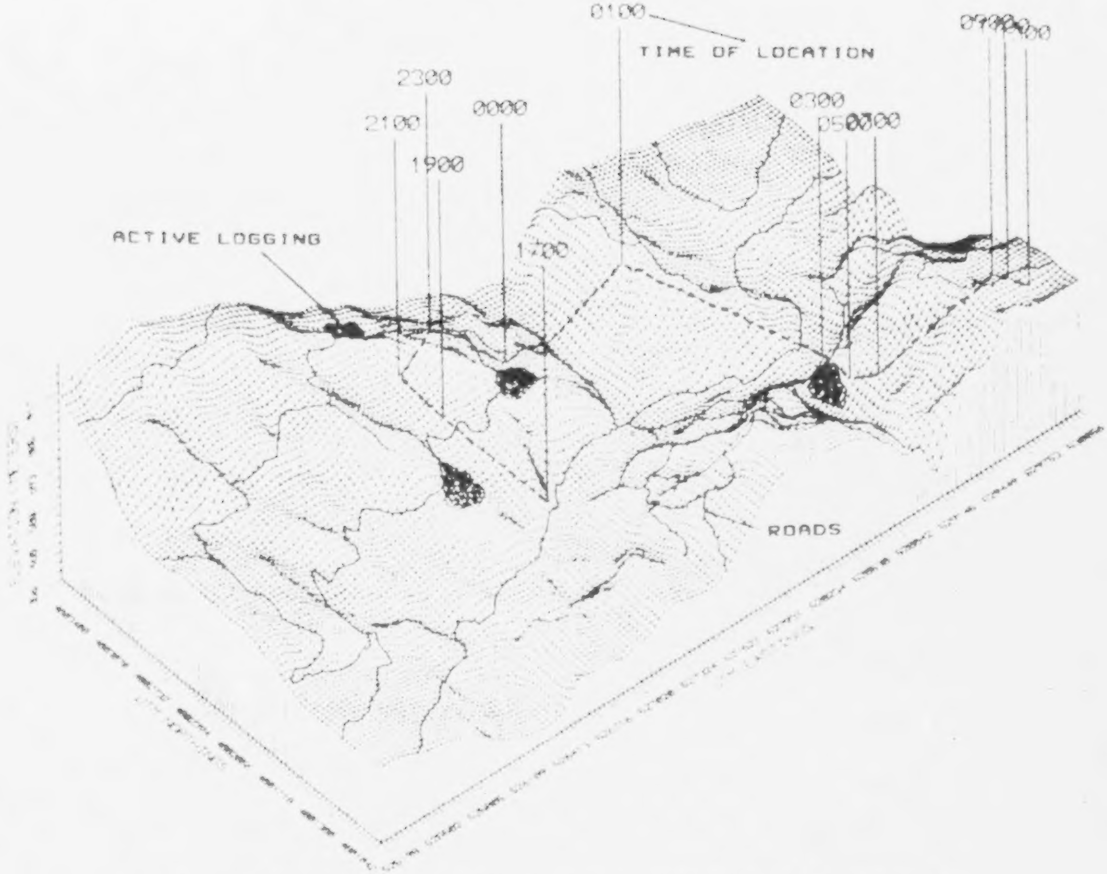

Figure 9. An example of continuous telemetry date incorporated into an elevation model showing road systems and human disturbances

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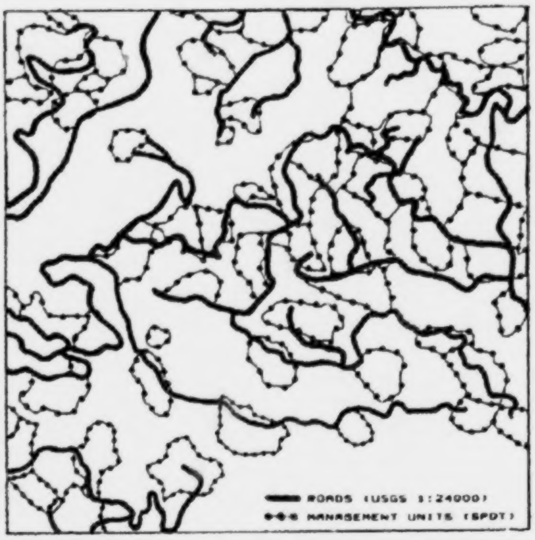

Figure 10. An example of fit from two different data sources.

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Integrated Management of Forestry and Wildlife Habitat with the Aid of a GIS-based Habitat Assessment and Planning Tool

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Abstract
The lack of integration between the activities of forest and wildlife managers has often led to conflict. In 1980 a cooperative research program between the B.C. Ministries of Environment and Forests was begun to help resolve one such conflict; the fate of valuable old-growth timber set aside as winter habitat for black-tailed deer and Roosevelt elk. The Habitat Assessment and Planning (HAP) tool, described here, is one of the products arising from that research.

The HAP tool consists of three modules: 1. Regional Priorities, 2. Watershed Assessment and 3. Management Options. These modules are designed to be used in an iterative fashion to increase the benefits of habitat management. The structure and operation of the tool is discussed.

Current development efforts for the HAP tool are focused on the Watershed Assessment module. Geographic information systems were used to model winter habitat suitability for black-tailed deer. The resulting suitability maps can assist in making decisions about habitat management needs.

Introduction

Habitat management is commonly used to achieve wildlife population objectives. However, wildlife managers frequently do not have control over the timing and placement of habitat manipulations that indirectly result from extensive forestry. Foresters have control but are often not aware of the effects of forestry on wildlife habitat. The resulting lack of integrated planning has often led to conflict. The Habitat Assessment and Planning (HAP) tool was developed to aid in determining the fate of old-growth forest stands that are deferred from harvesting because they are winter range for black-tailed deer (*Odocoileus hemionus columbianus*) and Roosevelt Elk (*Cervus elaphus roosevelti*). There are currently 50 000 - 100 000 ha of old-growth timber temporarily deferred from harvest with an estimated value of more than 50 million dollars (Ministry of Environment and Ministry of Forests 1983). The issue has been the subject of intensive research for the past two decades (Bunnell 1985, Nyberg *et al.* 1989).

Site-specific habitat management techniques can help alleviate some resource management conflicts (Nyberg *et al.* 1989), but managers have had little help with assessing the implications of their actions in the context of a watershed plan. Shifting focus from site-specific habitat management techniques to watershed management is difficult; each watershed has unique spatial properties associated with it. For example, the proximity of spring forage habitat will weigh heavily on the ultimate value of any management to improve winter habitat quality.

Another problem is that timber development and habitat management often occur at very different "operational" planning horizons. Wildlife managers should plan over time frames of at least 20 years and base their activities on both stands and watersheds. Timber managers treat stands or small groups of stands independently. The differences in spatial scale occur because animals must move to obtain resources and trees do not. Consequently, area-based planning is less difficult for forestry than it is for wildlife. The Habitat Assessment and Planning (HAP) tool assists in the integration of planning for these two values.

Institutional Framework

In most areas, on the south coast of British Columbia, responsibility for planning and carrying out logging and silviculture activities is delegated to forest companies that hold cutting rights while the Crown retains responsibility for fisheries and wildlife.

Initial development of the HAP tool has concentrated on the task of responding to 5 year "operational" forestry plans submitted by the companies to the Ministry of Environment for review and approval. The plans consist of paper maps showing proposals for stands to be harvested in each year, approximate road layouts, and lists of environmental constraints that will be followed. Due to the complex nature of land tenure in B.C. numerous different 5 year plans could be submitted for a single watershed. Habitat Protection Biologists and Technicians from the Ministry of Environment review the 5 year plans and suggest changes to the areas and scheduling of cutting to reduce the impact on wildlife habitat. This task is extremely complex and requires a good understanding of species habitat requirements, forest successional patterns and knowledge of local conditions. The current procedure is restricted in spatial and temporal scope yet it is time consuming and assessments of impacts on wildlife habitat are subjective.

Use of GIS and the HAP tool will help alleviate these problems by:

1. automating many of the manual aspects of the tasks;
2. identifying a small subset of the total area where site specific knowledge is critical; and
3. reducing the spatial and temporal complexity by modelling habitat quality.

Conceptual Framework

The HAP tool has been designed as a mechanism that provides information to managers which they can use to make decisions. The tool itself will not make decisions. Developing a "decision making" tool would require "rules" about biology and forestry that we can not presently develop. Decision making by managers that incorporates adaptive management procedures (Walters 1986) will eventually lead to an improvement in the way forests are managed.

In developing the HAP tool we have used the simplest possible models that provided useful and realistic results. An expert specifies those aspects of the system which he believes are important in arriving at the desired model output. This approach makes development, application and validation of the models easier and it allows managers to easily understand, and therefore believe in, the system (Bunnell 1989).

Wildlife ecologists have long understood and accepted that "game abundance should increase in situations where various types of food and cover come together" (Leopold 1933). This simple concept forms the core of the HAP tool. Previous attempts to incorporate habitat interspersion into wildlife planning, through the use of "interspersion indices" (e.g. Hienen and Cross 1983), failed to adequately represent wildlife habitat because they "added up" interspersion over large areas and did not represent the relationship among individual habitat polygons (stands). Adequate representation of spatial interspersion is possible only by processing habitat data while retaining its spatial integrity. This is only feasible through computerized map analysis (GIS). Useable microcomputer-based GIS software has recently become available and results already show the potential uses of GIS for dealing with the analysis of spatial interspersion of habitats (Lyon *et al.* 1987).

Description of the Habitat Assessment and Planning (HAP) Tool

The HAP tool is a series of microcomputer-based models that allows forestry and wildlife managers to incorporate the spatial and temporal aspects of wildlife habitat into operational forestry plans and habitat plans. The HAP tool helps managers to:

1. assess wildlife habitat suitability and the impacts of proposed forestry plans and activities on that habitat;
2. develop plans that minimize negative impacts and increase the benefit of forestry to wildlife habitat;
3. identify the risk of uncertain management actions and, where possible, the data required to reduce the uncertainty;
4. assess priorities for, and cost effectiveness of, habitat management projects; and
5. document the rationale used to make decisions that affect wildlife habitat.

The HAP tool consists of 3 component parts:

1. a regional priorities model;
2. a watershed assessment model; and
3. a management options model.

Each model has linked inputs and outputs that operate in an integrated and iterative fashion (Fig. 1). The regional priorities model is used to obtain a ranking of planning units (watersheds) in terms of the need for habitat management. For each high priority planning unit, the watershed assessment model provides an evaluation of the proposed forestry scenarios and assists with the specification of habitat management requirements. If requirements are identified the management options model is used to obtain a relative cost/benefit ratio for the proposed management action.

The regional priorities model is designed to priorize watersheds, within a region, in terms of their need for habitat management. The regional priorities model is an expert system-based decision hierarchy that attempts to find the limiting factor among 3 major questions (McNay *et al.* 1987, McNay and Page 1988):

1. are deer or elk a sensitive management issue in the watershed considering predation, societal demand, etc.;
2. is the topography capable of supporting deer or elk; and
3. is the current habitat suitability comparable to the topographic capability?

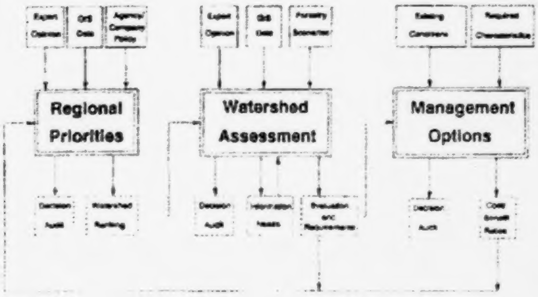


Figure 1
Framework forthe Habitat Assessment and Planning tool.

The watershed assessment model forms the core of the HAP tool. It is rule driven and allows the assessment of habitat suitability within watershed-sized areas. Watershed assessment is a stepwise process that may be iterative in nature. In the initial step, current habitat suitability for the wildlife species of concern is assessed. A series of proposed habitat manipulations (e.g. forest harvesting scenarios) are overlaid on the existing environmental conditions and changes in vegetation through time are determined. The habitat suitability under each scenario is compared with agency objectives. Input to the model includes large scale GIS data and proposed forestry plans. Model outputs are of 4 types:

1. *Data Inadequacy*: an identification of stands in the watershed where the available data are not sufficient to allow a reliable assessment of the present or future habitat conditions.
2. *Sensitive Stands*: identification of stands in the watershed where large changes in habitat suitability may result.
3. *Future Forecasts*: maps and tabular reports of the changes in habitat suitability through time.
4. *Documentation*: records of the results of the watershed assessment to aid in future evaluation of decisions.

The management options model determines the most cost effective methods of producing the habitat requirements identified by the watershed assessment model. Model inputs include the habitat conditions, resulting from the scenarios evaluated in the watershed assessment model, and the existing and required characteristics of the stands in question. Model outputs would be relative cost/benefit ratios of the proposed actions.

Watershed Assessment Process: An Example for Black-Tailed Deer on Vancouver Island

Winter habitat suitability for black-tailed deer was assessed for 11 000 hectares on southeastern Vancouver Island, British Columbia (described by McNay and Doyle 1987).

The first step in the watershed assessment process, evaluation of current habitat suitability, requires a model of winter habitat suitability for black-tailed deer as described in detail in Eng *et al.* (1989). The model (Fig. 2) is based on the following premises.

Snowfall on Vancouver Island exhibits a cyclic pattern with severe winters re-occurring at approximately 18 year intervals (Page 1990). Therefore, for long-term population viability, black-tailed deer require access to habitat that will enable them to survive both mild and severe winters. It has

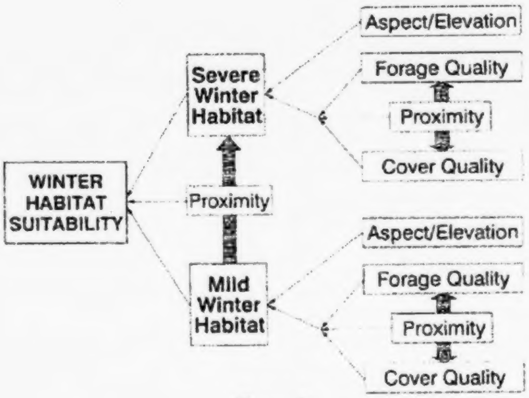


Figure 2
Winter habitat suitability model for black-tailed deer.

been found that accessibility of severe winter habitat is influenced by the migratory behaviour of individual deer. Deer exhibit three different migratory behaviours. Obligate migrators (individuals that move at the same time of year regardless of weather conditions) will spend the winter on severe winter habitat (i.e. for those deer severe winter habitat must be adjacent to mild winter habitat). Year-round residents (individuals that do not migrate) will move up to 0.75 km from mild winter habitat to severe winter habitat. Facultative migrators (individuals that move from summer to winter range depending on day-to-day changes in weather conditions) will move up to 3.0 km from mild winter habitat to severe winter habitat (McNay and Doyle 1987).

Within a single day deer require food and cover (primarily stands that intercept snow thus maintaining the availability of forage). The quality of habitat increases as the distance between these two attributes decreases. The habitat quality of a given location is also constrained by its aspect and elevation. High elevation north-facing slopes tend to receive more snow and retain it longer (i.e. lower quality) than do low elevation south-facing slopes (i.e. higher quality). The suitability of a given location differs between years because deer require better snow interception cover during a severe winter than during a mild winter and deer movements are more constrained by deep snow during a severe winter.

Current vegetation cover was classified using the methods described by Klinka *et al.* (1984). Each plant association and successional stage was rated from 0.0 to 1.0 for its ability to provide forage and snow interception cover. Combined aspect and elevation classes were also rated from 0.0 to 1.0 in terms of the constraints they placed on the ability of current vegetation cover to provide deer habitat. Ratings were based on judgements of field biologists familiar with black-tailed deer in the area.

Distance buffers from high quality forage and high quality mild winter and severe winter cover were calculated. The distance buffers were rated in terms of the likelihood that a deer would move that distance in shallow or deep snow. In severe winters with deep snow deer are reluctant to move out of cover (Fig. 3).

To create the winter habitat suitability map, ratings for forage quality, cover quality and the distance buffers were averaged and multiplied by the rating for aspect-elevation. Each polygon was categorized as adequate or inadequate habitat. Map layers representing adequate severe and mild winter habitat were overlaid creating a composite winter habitat suitability map (Fig. 4). Distance buffers around adequate severe winter habitat that included adequate mild winter habitat within 0.75 km and 3.0 km represent the migratory behaviour types of black-tailed deer, as described above.

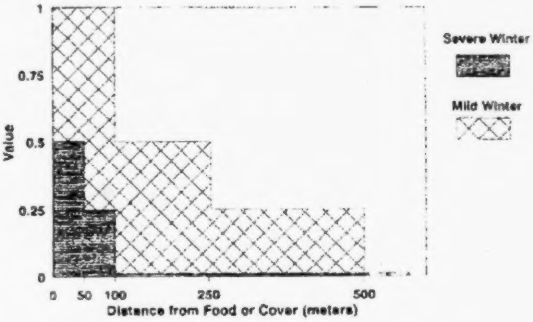


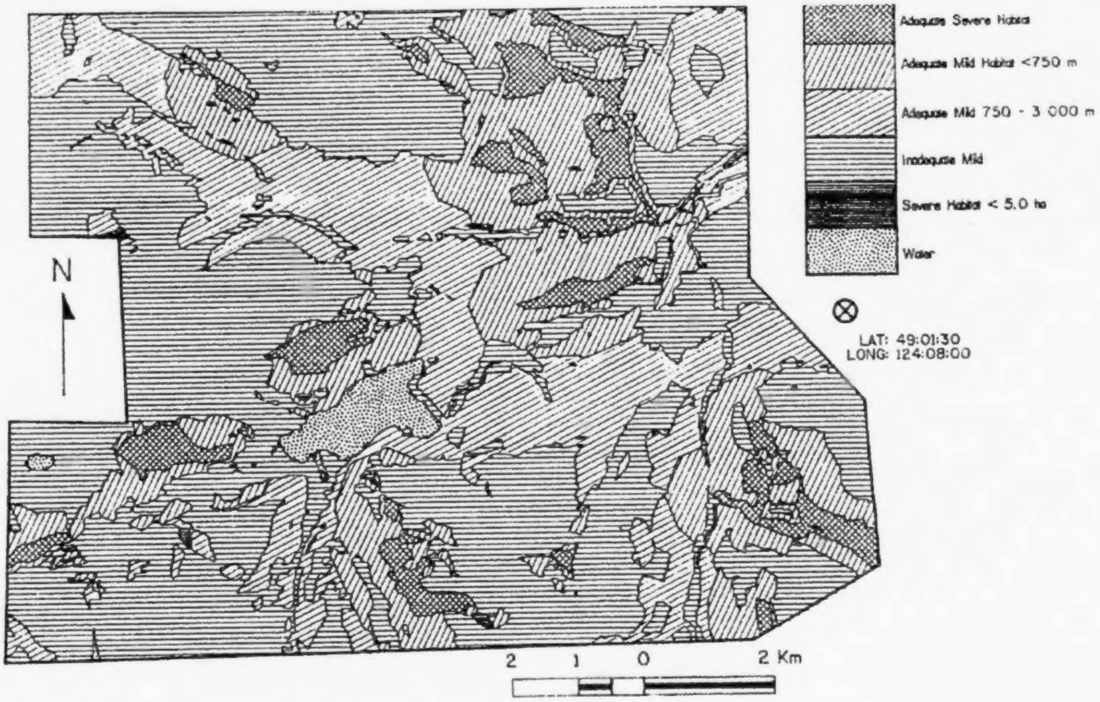
Figure 3
Distance buffers used in the suitability model.

A proposed habitat manipulation, in which most of the remaining low elevation old growth would be harvested between 1990 and 2010, was then assessed. The successional stage of each stand was changed to simulate conditions at the year 2020. A reassessment of winter habitat suitability in 2020 was conducted using the methodology outlined above (Fig. 5).

If the objective was to maintain the current quantity and distribution of winter habitat at 2020, then this objective would clearly not be met (see Fig. 6 and compare Fig. 4 and Fig. 5). The amount of adequate severe winter habitat will not decrease substantially from 1990 to 2020 (Fig. 6), even though most of the low elevation old growth will be harvested, because the model predicts that new severe habitat will develop at the edges between old second growth (which provide cover) and younger stands (which provide food). However, the amount of inadequate habitat will increase from 49.2% to 64.0% of the assessment area during the planning period and the amount of habitat suitable for supporting facultative migrators will decrease substantially (Fig. 6). Deer winter habitat will be severely fragmented, particularly in the western portion of the assessment area.

Opportunities and Constraints

The use of geographic information systems offers significant advantages over analog maps in the assessment and planning of wildlife habitat because daily and seasonal habitat interspersion requirements can be realistically modelled. Iterative assessments, comparing different scenarios, can be accomplished with minimal effort. The resulting output can be used to develop recommendations for changes to habitat manipulation scenarios and habitat enhancement programs.


Adequate Severe Habitat
Adequate Mild Habitat <750 m
Adequate Mild 750 - 3 000 m
Inadequate Mild
Severe Habitat < 5.0 ha
Water
N
LAT: 49:01:30
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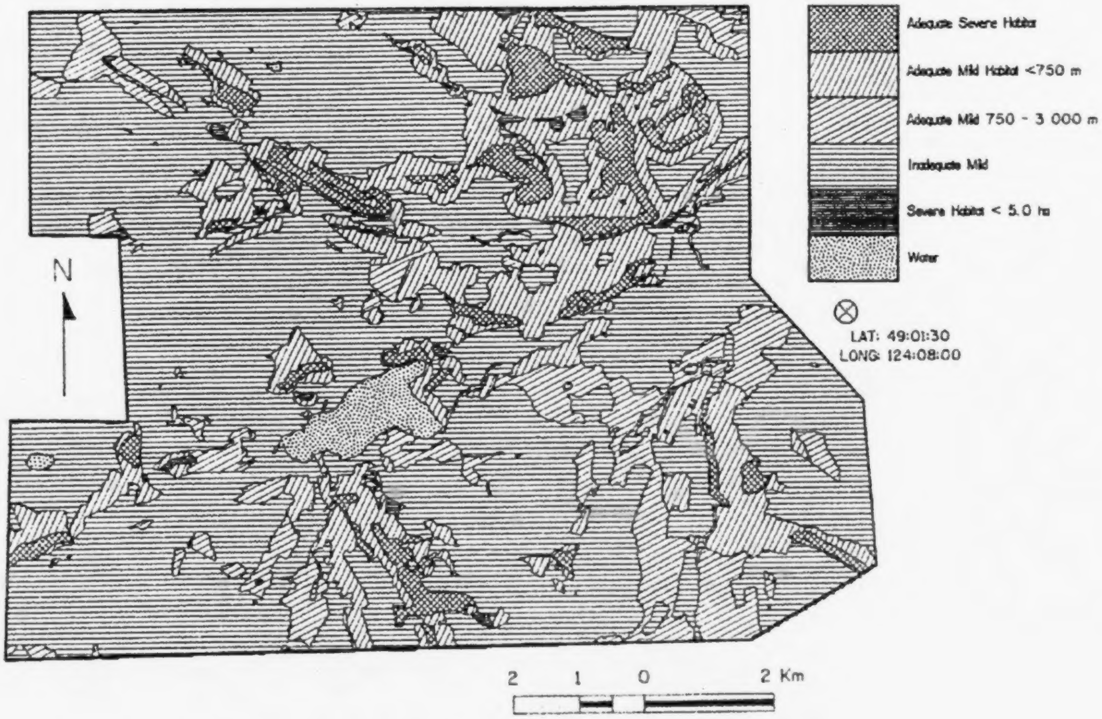
2
1
0
2 Km

Figure 4
Current (year: 1990) winter habitat suitability for black-tailed deer.


Adequate Severe Habitat
Adequate Mild Habitat <750 m
Adequate Mild 750 - 3 000 m
Inadequate Mild
Severe Habitat < 5.0 ha
Water
N
LAT: 49:01:30
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2
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Figure 5
Projected (year: 2020) winter habitat suitability for black-tailed deer.

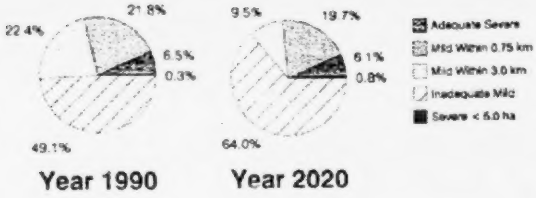

Figure 6
Summary of habitat in the assessment area.

However, there are several difficulties with the widespread application of this technology. Suitable models for management purposes (notably forest succession models) may be lacking and data may not be sufficiently detailed or reliable (current vegetation cover information). However, the most important difficulties relate to corporate and institutional attitudes:

1. effective use of the technology requires that wildlife managers explicitly state their habitat objectives and develop methods of comparing those objectives to the objectives of other resource sectors; and

2. management at all levels of industry and government must be willing to accept the cost and short term reduction in staff productivity that will be associated with the implementation of the technology.

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Making GIS Work

Session C2
We Did It Our Way - Making a GIS Usable

The Role of a GIS System in the Management of 900,000 acres of Industrial Woodlands

Updating and Maintenance of a GIS-based Forest Inventory

When Do We Reach The Leading Edge of Technology?

GIS'90 Symposium

Vancouver, British Columbia
March 1990

The Role of a GIS System in the Management of 900,000 Acres of Industrial Woodlands

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Abstract
Intensively managing woodlands for long-term resource production in a competitive forest industry requires timely and accurate information. S. D. Warren's Northeast Timberlands, located entirely in the State of Maine, employs 270 people including 35 foresters. Purchase of a GIS became necessary when our intensive management program began affecting 30,000 acres each year.

In addition to the data capture and groundtruthing of the base maps, the process of annual updates has been crucial in the successful implementation of this working GIS. The interaction between the field foresters and the mapping group is the driving force behind this five year old system. The information tracked includes harvesting, roadbuilding, planting, pre-commercial thinning, soils, application of herbicide, cover types, and land use zoning. Combinations of any of these features are used to make working documents for operational planning.

An Introduction to S. D. Warren

S. D. Warren's Northeast Timberlands is responsible for managing approximately 900 000 acres in the state of Maine. Annual planting, conifer release, pre-commercial thinning, and road construction impact on 30 000 acres of the land base. Historically, such changes required redrafting of forest cover type maps in order to maintain the base resource information. Silvicultural and harvest records were updated by color coding annual activities on office copies of the base maps.

Conceptual Beginning of Mapping System

Investigation into a more efficient system of updating and record- keeping commenced in mid-1981. The initial impetus came from a rapidly expanding silvicultural program and concurrent spruce budworm epidemic. The silviculture program required better records and the budworm problem necessitated faster and more accurate base map updating to reflect new road construction and potential mortality areas. Emphasis was placed on providing working documents and planning tools for the field foresters.

Choosing a Mapping System

With those basic needs in mind, several GIS turnkey systems were evaluated through contact with users, review of literature, and review of system costs and personnel requirements. In March, 1984, a trial project using a 'typical' township was implemented through GeoBased Systems, Inc. of Raleigh, North Carolina. The project was designed to test basic mapping features, complex mapping features, and tabular data. Basic activities addressed were data entry ease, editing capabilities, plotting at various scales, and shading to highlight desired polygons. The complex features were an overlay routine and corridor generation. Tabular data bases were constructed for the type map and for a soils map.

The decision was made during the fall of 1984 to purchase two GeoBased systems - one for Northeast Timberlands and one for Southeast Timberlands. Both systems were delivered and installed during the spring of 1985.

Training on the Northeast system commenced in May 1985 for three operators, who remained in the learning mode throughout the summer of 1985. During the training period, "real data" was employed for plotting, editing, and creation of new layers. By using the actual type maps for training two important benefits were obtained: how the system handled the data that would be the foundation all other layers; and, it gave the operators the chance to quickly change any features in the data before the contractor finished the total data entry project.

Configuration of the System

1985: DEC PDP 1173, Cipher Tape Drive, CalComp 1073 Plotter.

1987: First PC station Compaq 386, 16 MHz, 130 Mb hard drive with a routine to translate from PDP.

1988: Addition of another workstation Compaq 386, 20 MHz, 300 Mb hard drive and retiring of the PDP 1173

Present: Network of 4 workstations: the Compaq 386, 300 Mb hard drive as the file server; the original Compaq 386, 130 Mb hard drive; a Compaq 286, 20 Mb hard drive; and a Compaq 386, 40 Mb hard drive located in the research department; the Cipher tape drive is used to back up the system; CalComp 1073 Plotter.

1990+: Emphasis will be on placing a workstation in each of the district offices. This will require a larger fileserver such as the SUN workstation or the IBM AS400 and an applications oriented version of the GeoBased software for our field people.

Mapping Conventions

Flexibility in producing outputs is a must. End users will come up with ideas for products that the system operators will not foresee. File structure will be the deciding factor in whether these projects are possible. Naming conventions for files, label values for line and polygon features, and color assignments should be created well in advance. To help in this endeavor, visit a user of the system in question and discuss how each system handles such things.

Operational Use of Northeast Timberlands GIS

During the first three years of use, the activity of the system centered around entering harvest history data and providing field personnel this information in the form of 'cut maps'. The maps consist of ten years of harvest polygons shaded and overplotted on base cover type maps that have been updated yearly for cover type changes and roadbuilding activities.

The process to update the cut maps is a yearly occurrence. Beginning in February, the field foresters return 1:15 840 maps or aerial photos to the mapping department with updates drawn on them. The foresters use high altitude orthographically-corrected aerial photographs if they are available that particular year. Otherwise, the foresters take photographs with a 70 mm camera from a small plane and use slides to project onto a base map for updates. It takes the mapping department seven months to update all the township maps that need work each year. Historically, each year's harvesting has changed at least 50 of the 78 townships that we own land in. Not only does the update process provides us with current maps but the number of acres harvested by type can be determined during the overlay process. These numbers can be used to update our growth and yield model.

Now that the annual cut update cycle has become a standard procedure and the computer display and processing times have increased tremendously, other layers have been added and other projects are proposed continuously. Plantations have been incorporated into the base maps; pre-commercial thinning and herbicide layers have been digitized; 600 000 acres of soils classification are completed; and the land use zones mandated by the state may be overplotted. The other feature that has become more powerful with advancements in technology is the link between the graphic information in the system and the tabular database. GeoBased Strings uses INGRES as its database language. This is a relational database with SQL or QUEL as its language. Data entry forms can be created; queries on the tabular data can be made easily; and standard map data can be linked to secondary tables.

The plans for future developments include incorporating topographic information into the soils data for roadbuilding applications and placing applications oriented stations in each of the district offices as mentioned before.

Special Projects

The ability to assist many different managers with special projects have been a secondary benefit of the GIS system. Many presentations have been supported by the graphics provided by the mapping department. Everything from procurement zone strategy to retirement party props have been created.

The GIS system has assisted our real estate forester in many of his transactions. Although each transaction is very different, the questions asked each time are very similar: how many acres by type are in the parcel in question; how many feet of shoreline; and, how many acres or feet of roads are included in the parcel.

Summary

The success of this working GIS has been the constant progression of the system. Initially it met the needs of the field foresters who needed more timely data for operational planning. GeoBased Systems continues to provide software and hardware innovations that allow our mapping department to make improvements in our process. Continuous improvement to existing information and addition of new data allows us to provide working documents to our field people to make informed decisions.

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Updating and Maintenance of a GIS-based Forest Inventory

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Abstract
The spatial analysis capabilities provided by geographic information systems (GIS) hold tremendous potential to improve design of forest management activities. Realization of that potential, however, is contingent upon maintenance of accurate and up-to-date descriptions of the forest being managed. Forest inventory update measures necessary to provide such descriptions are simple in principle, but complex and intricate in practise. Eight years of GIS use in New Brunswick has lead to development of a number of update procedures which use GIS utilities in managing change information to maintain the integrity of the forest resource description. This paper reviews the roles, types, and principles of the updating undertaken in New Brunswick and illustrates the design and mechanics of update procedures currently in place. The nature of these activities point towards a number of substantial changes in forest inventory practises which many evolve as GIS technology becomes the primary tool of resource information management.

Introduction

Geographic Information System technology is becoming a common place tool in Canadian forestry. GIS acquisition is often justified on grounds that it will strengthen forest management by supporting sophisticated planning systems which can account for the spatial element of the resource. GIS applications like route allocation, harvest scheduling, and digital terrain analysis are attractive indeed; however, realization of their potential pay offs is contingent upon the information they require being up-to-date and accurate with respect to the forest being managed. A structured and comprehensive update mechanism is necessary to maintain the integrity of the resource description (inventory). The absence of such a system can seriously undermine the ability of GIS to perform as advertised and actually improve forest management.

On the surface, forest inventory updating seems simple enough, and any creditable GIS package supports an 'update' function. As such, updating may get little attention, especially in contrast to more glamorous GIS applications involving spatial modelling and the like.

In New Brunswick, where GIS use in forest management began in 1982, we have learned that updating a GIS-based forest inventory is any thing but simple and that it warrants considerable attention if it is to be well executed. My intent here is to convey some of the New Brunswick experience in updating so that others can benefit in similar undertakings of their own. Specifically, I will review the role, types, and principles of the updating we undertake and will go on to illustrate the design and mechanics of the operational updating procedures we have developed. In closing, I will look ahead and speculate on some profound changes to forest inventory procedures which may evolve as GIS technology becomes the primary tool of resource information management.

Roles of Forest Inventory Updating

Forest inventory updating plays three distinct and critical roles in the forest management process.

First, forest management strategies are selected for implementation based on the expected forest level response to specific stand level treatment regimes which include harvesting, silviculture, and protection. For expectations to materialize, two conditions must be met: (a) the proposed regimes must, in fact, be implemented as planned, and (b) the local stand response to intervention must be consistent with forecasts used in the initial forest management strategy design. In the absence of a systematic and comprehensive update mechanism to detect when these conditions are not met, there exists a high probability of serious divergence between what the forest is expected to produce and what it actually can produce.

Second, fundamental to the development of effective and efficient forest management plans are high quality stand development forecasts. Fundamental to high quality stand level forecasts is accurate initialization of stand characteristics. Without a suitable update mechanism in place, stand initialization data quickly become obsolete, which renders stand level forecasts highly uncertain. Stand level uncertainty translates directly, and sometimes compounds, into uncertainty at the forest level (Wang 1986). Significant uncertainty at the forest level undermines the value of sophisticated planning tools when decision-makers have insufficient confidence in analysis results to act upon them. Thus, the tremendous investment in, and potential value of, GIS technology may be wasted if updating is not carefully conceptualized and diligently implemented.

Third, the direct investment in the forest resource through public and private silviculture expenditures has increased dramatically over the past decade. So, too, have the auditing requirements of funding agencies who, justifiably, want to ensure their investments are sound. Continued investment may depend upon the degree to which benefits of past investments can be unequivocally documented and demonstrated. Incomplete and ill-conceived update procedures limit reporting of past investment performance and, thereby, may jeopardize future investment possibilities.

For these reasons, implementation of GIS technology in New Brunswick forestry has included considerable effort to design, build, and implement a comprehensive update mechanism in its forest resource information system.

Types of Forest Change

The first step in design of New Brunswick's update procedures was to identify the types of change which updating must reflect. Change types were categorized and distinguished based on: (1) how the change affects the resource, (2) how the change can be observed and measured, and (3) the implications of the change with respect to forecasting stand development. On these grounds, slow changes were differentiated from fast ones. Slow changes stem from natural stand development and include volume change, crown differentiation, and species succession, all of which are caused by individual tree growth, mortality, and between-tree competition. In relative terms, such changes are slow, continuous, and, to some extent, predictable in that these natural stand dynamics are precisely what most stand growth models are designed to predict. The quality of the forecasts hinge upon the structure of the growth models used and upon the accuracy of the stand characteristics with which the models are initialized. The role of updating in this context is to provide accurate initialization to growth models.

Fast changes in the forest condition are quite different in nature and effect. They result from sudden, discrete events rather than the continuous process of stand development associated with slow changes. Fast changes are more readily detected and measured and include partial and complete harvesting, road construction, fires, defoliation, and most silviculture activities. Such events quickly and dramatically alter stand conditions to initiate new development patterns quite distinct from those expected under stand conditions prior to the change. In this sense, fast changes are more critical for updating to capture because they initiate abrupt developmental shifts in affected stands.

As a consequence, the New Brunswick effort first turned to addressing fast changes.

Update System Characteristics

In designing an update system to capture forest resource changes, seven characteristics were identified as being critical to the system's architecture.

1. All changes must be geographically referenced so that specific events can be unambiguously linked to specific locations and vice versa. This geographic linkage provides support for both site specific and event specific queries and answer questions like: 'What events have occurred at location X?' and 'Where are all the occurrences of event Y?'
2. There must be no loss of information regarding stand conditions prior to any and all changes. Such historical information is essential to reconstruct past forest conditions at a selected date for the purpose of assessing change. Further, past conditions must be available when they influence future development, as is the case where pre-cut stand composition affects post-cut stand composition and development.
3. Flexibility must exist in the architecture to accommodate new events as they are operationally introduced. For example, commercial thinning and fertilization are not practiced operationally in New Brunswick. If and when they are implemented, the update system should capture them (or any other new activity) with no change in design.
4. The system must accommodate continual updating over many years (one rotation at minimum) and must efficiently manage cases where multiple events occur in a stand over time and where stands are continually subdivided as different treatments are imposed (e.g., partial planting of a harvest block or planting of many species or stock types within a harvest block).
5. Selective queries should be supported which allow efficient searches through the update system accessing only those data relevant to the questions posed.
6. Events which change stand conditions should be linked to descriptions of stand response. Thus, survey information should be incorporated into the update system and be referenced to the locations in which the surveys were carried out. This enables reporting not only what changes have taken place, but the stand response to those changes as well.
7. Complete stand specific histories should be maintained from the time of harvest or disturbance through all subsequent events which occur in the stand. These histories should be structured in such a fashion to allow their incorporation into any future inventory efforts which may be undertaken.

Illustrative Cases of Updating System
Stand Diary System

In 1984, those involved in GIS use in New Brunswick forestry undertook development of an operational updating system which possessed the desired characteristics and could efficiently manage information about the important forest resource changes.

Attention first turned to managing fast changes since these were viewed as having the most profound effect on the resource. This work lead to a stand diary concept for managing present and historical information about fast changes due to harvesting, wildfire, road construction and silviculture. The general architecture of the system, presented in Figure 1, is comprised of four major components: (1) a present inventory, which contains geographic and descriptive files about the current state of the resource, (2) an historical inventory consisting of geographic and descriptive files about the state of the resource prior to change;, (3) event description files which contain the specifics of the events which caused the change in the resource, (central to the system is the assignment of unique reference numbers for each event which has occured), and (4) the stand diary file which stores the reference numbers to associate fast change events to the stands which they affect. This last file records and accumulates information over time on a stand-by-stand basis and does indeed function as a diary, chronicling change events in the life of each stand.

All files in the system are arranged in relational file format, with the event reference numbers providing the primary link between event descriptions and the stand diary, and conventional stand numbers providing the secondary link between the stand diary and present and historical inventories. The relational architecture enables spatial and tabular query access of any and all data stored in the overall package. This provides power and flexibility to service queries which are stand specific, event specific, geographically specific, or are any combination thereof.

To illustrate, consider two requests which might arise in validating plantation growth forecasts: (1) 'What is the mean and frequency distribution of current annual height increment at age five on 1984 black spruce bareroot plantations established on former mixedwood stands harvested under a full-tree harvest system?' (2) 'Geographically map and differentiate the top, middle, and lowest performing thirds of that population.'

These extremely complex searches, virtually impossible under our previous inventory management, become tractable with GIS technology and the stand diary system portrayed in Figure 1. The search would commence in the historical inventory to find past mixedwood harvests, then proceed through the stand diary file to find full-tree operations in the harvest file and 1984 black spruce bareroot plantations in the planting file. Height increments would then be summarized for the appropriate plantations in the plantation survey file. The results of the search and summarization would travel back through the stand diary to the

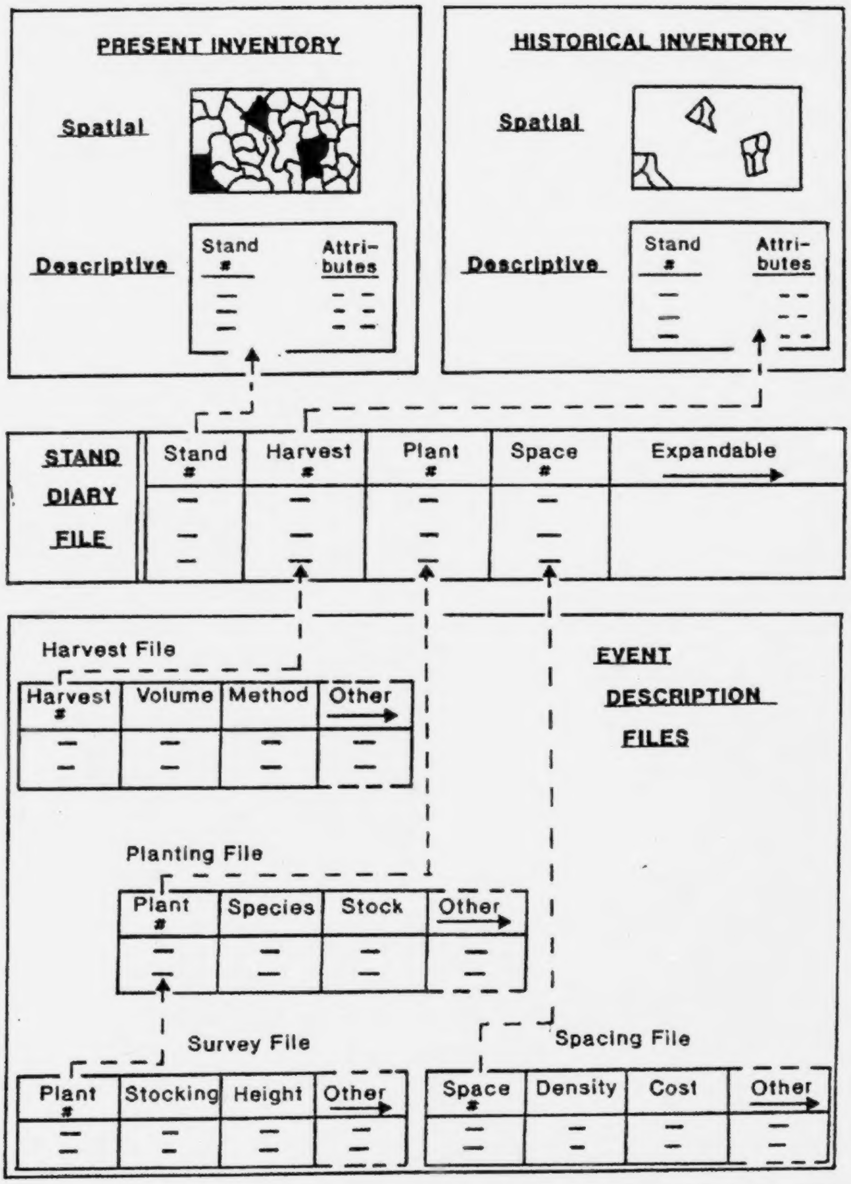

PRESENT INVENTORY
Spatial
Descriptive
Stand #
Attri-butes
HISTORICAL INVENTORY
Spatial
Descriptive
Stand #
Attri-butes
STAND DIARY FILE
Stand #
Harvest #
Plant #
Space #
Expandable
Harvest File
Harvest #
Volume
Method
Other
EVENT DESCRIPTION FILES
Planting File
Plant #
Species
Stock
Other
Survey File
Plant #
Stocking
Height
Other
Spacing File
Space #
Density
Cost
Other

Figure 1. General archiecture of the stand diary update system. Dashed arrows indicate relational links between files.

present inventory to map and differentially shade the subsets of the population performing at different rates of height increment.

Flexibility in the system is accomplished by expanding the diary horizontally as new events occur, expanding the diary vertically as new stands are created, and adding more event description files as new surveys are undertaken and/or new types of events take place. Despite these expansions to accommodate more complexity, the system architecture remains intact.

Figures 2, 3, 4, and 5 are presented to illustrate how the stand diary system is built up for a simple case involving three years of updates for harvest, planting, and spacing operations following initial inventory compilation in 1990. At the outset, the present inventory contains four mapped stands and their associated descriptions; the historical inventory is empty, as are the stand diary and event files (Figure 2).

In 1990, harvest A is carried out (Figure 3). It is mapped and entered in the harvest event file as a full-tree operation in which 150 m³/ha were removed. The GIS update and clip

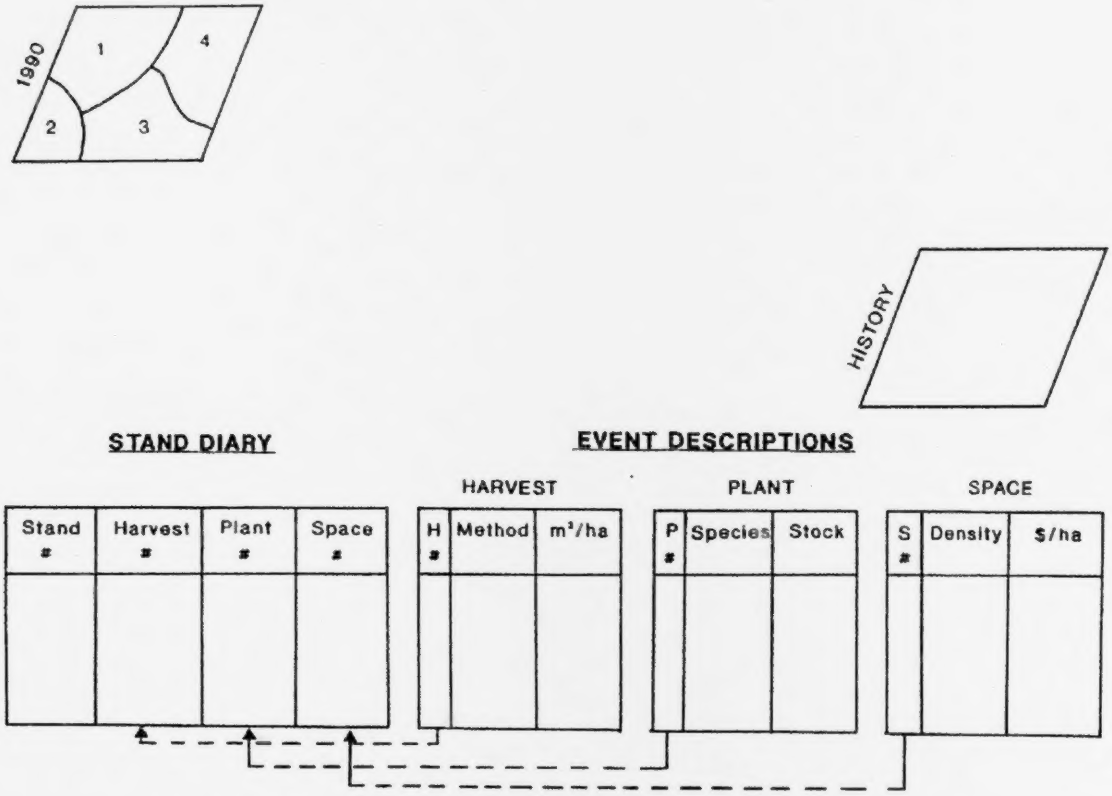


Figure 2. Initial structure of stand diary system assuming initial inventory compilation in 1990. Dashed arrows show relational links between files.

(ESRI 1989, ARC/INFO terminology) functions are executed to update the inventory to 1991 and to store pre-cut stand conditions in the historical inventory. The newly created stand (#5) is registered in the stand diary file and identified as arising from harvest block A (Figure 3).

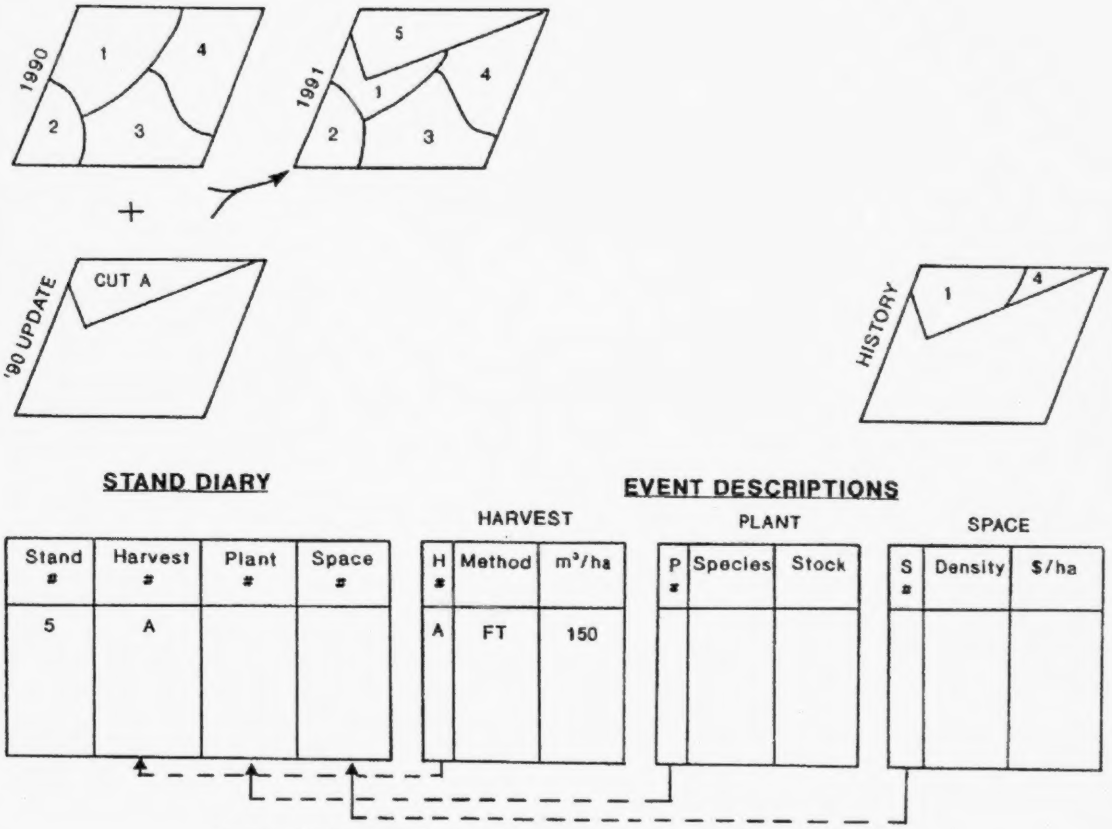
In 1991, the update process continues as plantation X is established and harvest B is carried out (Figure 4). The harvest event file records B as a 200 m³/ha trailcut and the plantation file records X as black spruce 2-2 bareroot stock. Update, clip, and append GIS functions are invoked to update the inventory to 1992, extract the pre-cut stands coincident with cut B, and accumulate the history, respectively. Two new stands are entered into the stand diary: #6, because plantation X has made it distinct from its parent (#5), and #7, because it is a newly-created harvest block.

The final year in the sequence is 1992 where harvesting C, planting Y, and spacing Z are carried out (Figure 5). The harvest file now includes C as a 100 m³/ha full-tree cut, the plantation file includes Y, a jack pine 2-0 bareroot plantation, and the spacing file contains Z, where stem density is reduced to 2000 per ha at a cost of $500 per ha. The update, clip, and append functions are performed to modify the present and historical inventories in appropriate fashion. The stand diary contains two new entires: #8, arising from plantation Y and #9, created by harvest C. Further, the stand diary records for stands #5 and #6 are assigned the spacing Z entry to reflect the spacing which has occurred therein. The process continues over time as additional updates take place. The event description files expand as more activities occur, new entries are made in the stand diary file as activities create new stands, and the historical inventory grows as it accumulates original resource conditions prior to change.

Defoliation Update System

While the stand diary system manages changes which occur on a localized basis, other important fast changes occur more extensively across the entire resource. In New Brunswick, the most noteworthy extensive change is defoliation of softwood stands caused by the spruce budworm. Annual defoliation can significantly reduce the foliage complement of stands and, thereby, trigger serious volume growth loss and accelerated mortality. To the extent that stand growth response to defoliation can be accurately forecast, forest protection and harvest scheduling can be designed to limit defoliation caused losses. To the extent that realistic growth models and accurate defoliation data are available on a forest-wide basis, such forecasts can be made.

Figure 6 presents 25 year growth data for three balsam fir stands to illustrate the effect of defoliation on stand growth



STAND DIARY

Stand #	Harvest #	Plant #	Space #
5	A		

EVENT DESCRIPTIONS

HARVEST

H #	Method	m^3/ha
A	FT	150

PLANT

P #	Species	Stock

SPACE

S #	Density	$/ha

Figure 3. Management of stand diary system through first year of update (1990).

and the importance of recording defoliation occurrence in predicting that effect. The three stands, structurally identical at first measurement in 1960, manifest uniform volume growth up to 1975. If, at that time, a decision was made to harvest one stand in 1975, one in 1980, and one in 1985, there was no obviously superior sequence as all stands had grown similarly up to 1975 and in 1975 all had similar volumes.

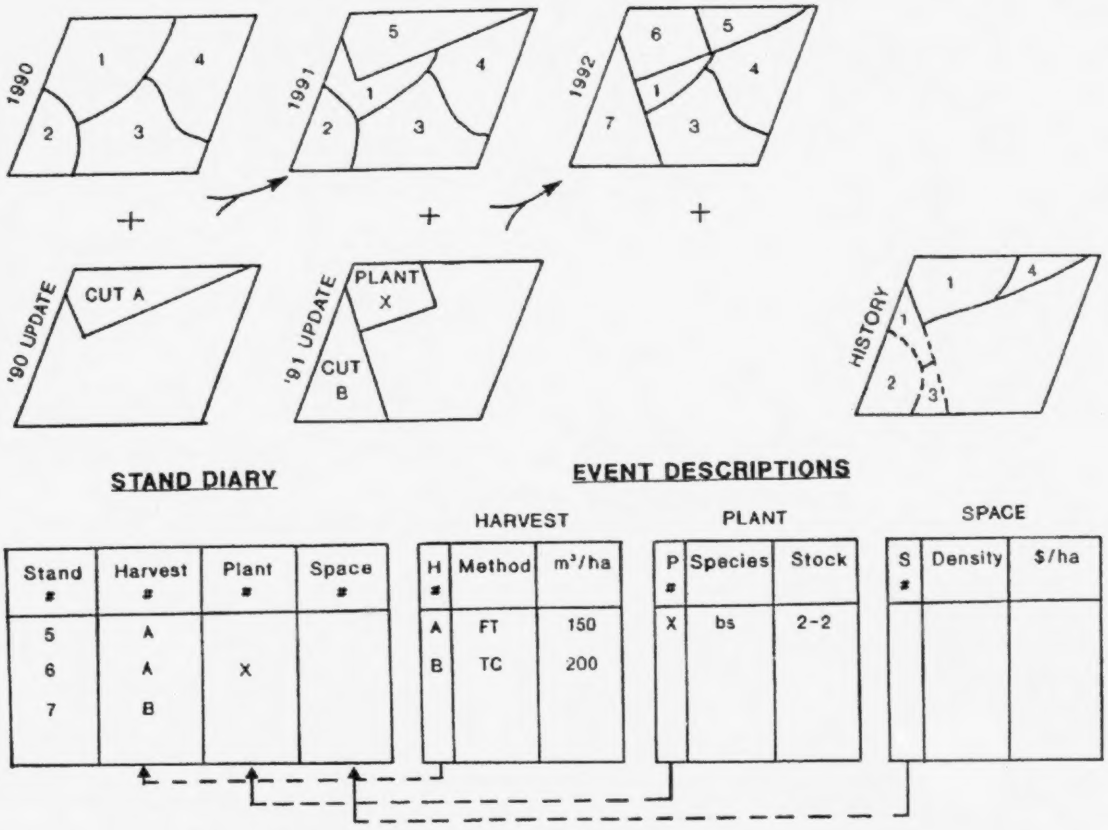
Between 1975 and 1985, dramatic growth differences between the three stands are apparent and the harvest sequence decision takes on considerable importance. The most productive sequence would have been to harvest stand C in 1975, stand B in 1980, and stand A in 1985. Of course, the choice is easy once the yield patterns are known, but the 1975 scheduling decision must be made in anticipation of future yields, without knowledge of past ones. Anticipation of the growth differences between the three stands is possible only if the defoliation sustained by each stand is examined. Figure 7 reveals that stands A, B, and C sustained light, moderate, and severe defoliation, respectively, and this information provides the basis for predicting the growth differences manifest by the three stands.

Because of the obvious importance of defoliation in forecasting stand growth for design of productive harvest and protection schedules, an update mechanism was developed to enter defoliation data into the GIS and to associate these data on a stand specific basis across the entire inventory. Figure 8 illustrates the manner by which that process is accomplished.

Defoliation occurrence is geographically recorded in the annual aerial defoliation survey undertaken in the province each July following the period of spruce budworm feeding.

The mapped survey results are digitized as defoliation polygons in the GIS and registered in the inventory coordinate system. Point-in-polygon overlays are then performed to associate each stand in the inventory with the annual defoliation level it sustains. While stands are normally stored as polygons in the inventory, they are represented as points in the defoliation overlay to expedite data processing and to avoid expansion of data storage requirements associated with polygon-on-polygon overlays. Because of relatively small stand size (7 ha) and the imprecision of defoliation boundaries, this point representation of stands in the defoliation overlay is a logical approach.

As shown in Figure 8, the annual defoliation overlay process accumulates defoliation occurrence in each stand's attribute description. This provides precisely the information necessary to anticipate defoliation caused growth differ-



STAND DIARY

Stand #	Harvest #	Plant #	Space #
5	A		
6	A	X	
7	B		

EVENT DESCRIPTIONS

HARVEST

H #	Method	m^3/ha
A	FT	150
B	TC	200

PLANT

P #	Species	Stock
X	bs	2-2

SPACE

S #	Density	$/ha

Figure 4. Management of stand diary system through second year of update (1991).

ences demonstrated as being fundamental to judicious harvest scheduling by the Figure 6 example.

This type of update is quite straight-forward, but was impractical, prior to GIS maintenance of the forest inventory. While GIS technology has enabled operational forest-wide defoliation update, it has had two other beneficial spin-offs. First, the ability to assign defoliation occurrence on a stand-by-stand basis has elevated the importance and utility of high quality defoliation detection. This has accelerated research into new methodology for defoliation detection using electronic sensors. Second, the availability of stand specific defoliation data on a forest-wide basis has increased the requirement for defoliation-sensitive stand growth models.

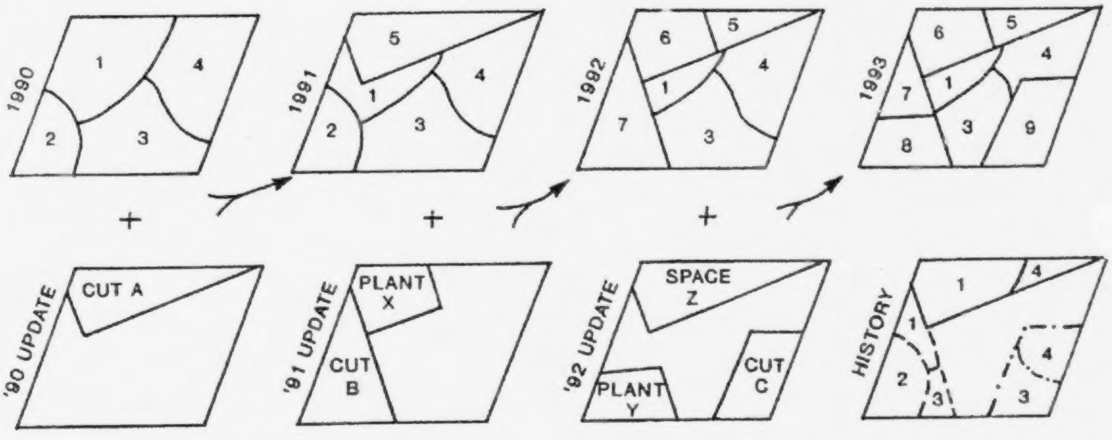
Of course, research into both defoliation detection and growth forecasting has been underway for sometime, but the research efforts have recently accelerated because GIS technology has paved the way for application of research results into operational forest management practises. The effect of GIS in this regard may be one of the most profound and far-reaching benefits of the technology.

Stand Vigor Updating

The final example of updating the New Brunswick GIS-based forest inventory involves characterizing stand vigor as it relates to future volume increment. Unlike the stand diary and defoliation updating procedures, stand vigor updating is not yet an operational practise. However, because its development is being earnestly pursued at present and because of its enormous potential to improve forest management practises, it warrants discussion here.

Accurate stand growth forecasting is essential for the design of productive harvest, silviculture, and protection activities. In fact, it can be strongly argued that stand growth forecasting is the most critical element of forest management design. Inventory design in New Brunswick, and probably much of Canada, has traditionally focussed on accurate estimation of the current timber growing stock. While current volume estimation is important, of equal importance is the ability to forecast future changes in stand volume. The Figure 6 example demonstrates the point clearly for three stands and the message pertains to the operational context where harvest choices are made amongst many thousands of stands.

Supporting information about future stand yield necessary to make appropriate choices in the operational context is poorly provided by the New Brunswick forest inventory in its present form. Consequently, efforts have been made to enhance the forest resource description with additional information relating specifically to stand volume increments.



STAND DIARY

Stand #	Harvest #	Plant #	Space #
5	A		Z
6	A	X	Z
7	B		
8	B	Y	
9	C		

EVENT DESCRIPTIONS

HARVEST

H #	Method	m³/ha
A	FT	150
B	TC	200
C	FT	100

PLANT

P #	Species	Stock
X	bs	2-2
Y	jp	2-0

SPACE

S #	Density	$/ha
Z	2000	500

Figure 5. Management of stand diary system through third year of update (1992).

Stand growth is largely governed by the structure of the stand canopy. Since air or space-borne electronic sensors characterize stand canopys through spectral reflectance, remote sensing seems the most promising with respect to volume increment characterization.

To pursue this possibility, an applied research and development project has been jointly undertaken by the New Brunswick Department of Natural Resources (DNR), Forestry Canada, the Canadian Centre for Remote Sensing, and the Universit/ de Moncton at Edmundston. The primary objective is to investigate the relationship between spectral reflectance and volume growth in merchantable spruce/fir stands. In the event that strong correlations are found, the second objective is to operationally integrate the raster remote sensing data with the GIS vector-based inventory so that reflectance values can be used through correlation to individually assign volume increment attributes to all spruce/fir stands in the inventory.

Initial research indicated the presence of a correlation between periodic stand volume increments and certain spectral bands recorded by the LANDSAT IV Thematic Mapper sensor (Ahern et al. 1989). Figure 9 shows the general form of the correlation using TM band 4 and 7 ratios which, at present, is the most promising independent variable. Research is continuing to confirm the existence and quantify the strength of the correlation. Being optimistic about the outcome of the research, DNR has proceeded to develop the mechanism to embed TM reflectance data into the forest inventory. Figure 10 (adapted from Erdle, 1989) presents the methodology under development.

The main data sets are: (1) the vector-based digital forest inventory containing locations and photo-interpreted attributes (species, maturity, crown closure, etc.) for all stands in the forest and (2) raster-based imagery containing 30 m x 30 m pixels, each with its associated spectral reflectance values.

The first step in the process is to geometrically register the two data sets to achieve geographic coincidence of corresponding features. Next, an overlay is performed resulting in the assignment of each pixel to the stand in which it resides. This, in turn, assigns reflectance values to each stand, providing the necessary independent variable for processing through the correlation equations. The result is a stand-by-stand prediction of stand vigor, expressed by the current volume increment. Finally, the computed volume increment is appended as an additional attribute in each stand's descriptive record.

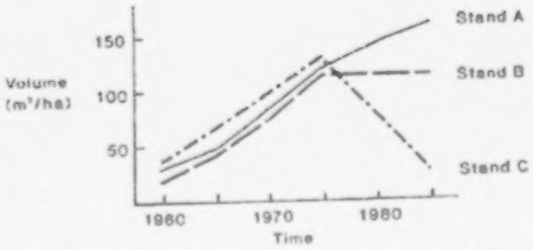


Figure 6. Volume development for three balsam fir stands.

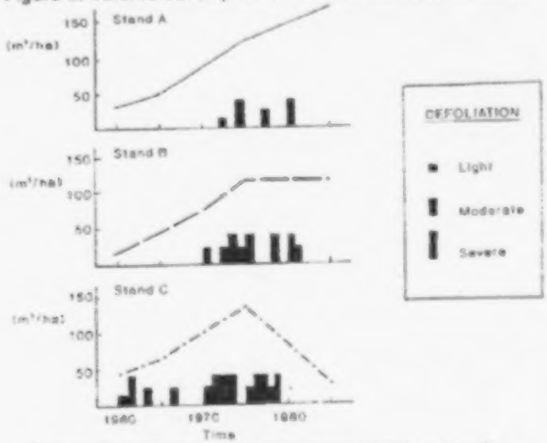


Figure 7. Annual defoliation patterns causing growth differences in balsam fir stands A,B, and C.

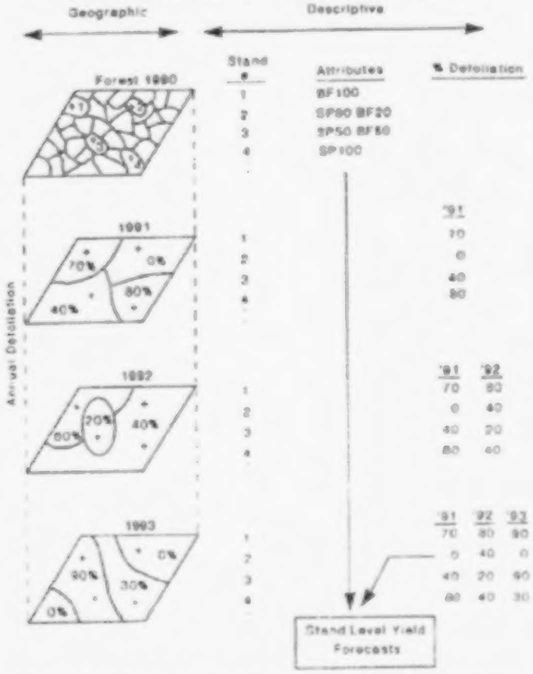

Geographic
Descriptive
Forest 1990
1991
1992
1993
Annual Defoliation
70%
0%
40%
80%
20%
60%
90%
30%
Stand #
Attributes
% Defoliation
1
2
3
4
BF100
SP80 BF20
SP50 BF50
SP100
'91
'92
'93
70
0
40
80
20
90
30
Stand Level Yield Forecasts

Figure 8. Point-in-polygon overlay of defoliation on forest stands. Stands are represented as points and overlaid with maps of annual defoliation. Defoliation values for each year are appended to each stand's attributes. Resulting data provide input to stand growth models.

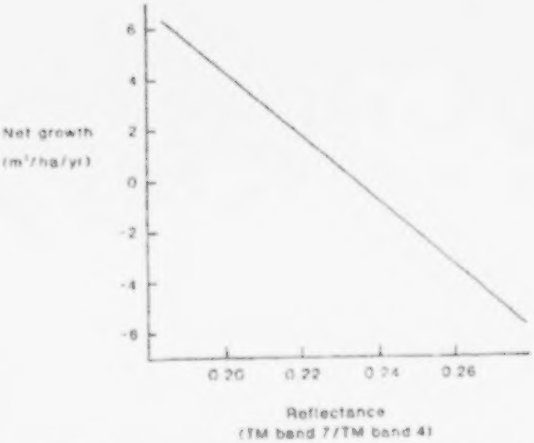
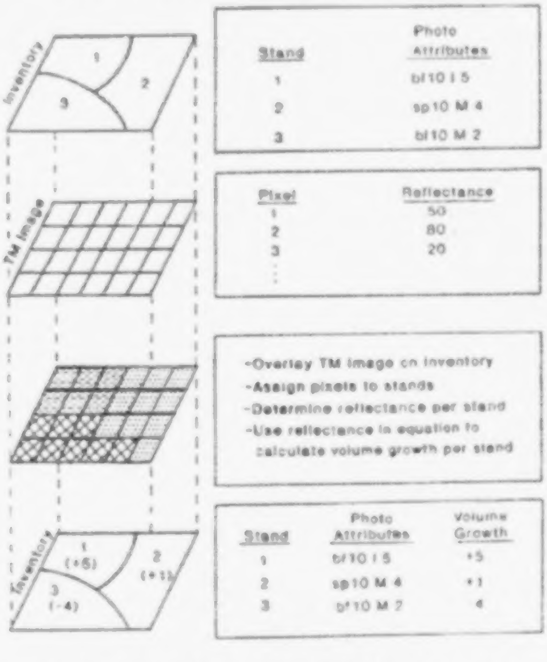


Figure 9. Correlation between spectral reflectance and net stand volume growth (from Ahern et al. 1989).


Inventory
TM Image
Inventory
1
2
3
(+5)
(+1)
(-4)

Stand	Photo Attributes
1	bf10 I 5
2	sp10 M 4
3	bf10 M 2

Pixel	Reflectance
1	50
2	80
3	20
⋮	

-Overlay TM image on inventory
-Assign pixels to stands
-Determine reflectance per stand
-Use reflectance in equation to calculate volume growth per stand

Stand	Photo Attributes	Volume Growth
1	bf10 I 5	+5
2	sp10 M 4	+1
3	bf10 M 2	4

Figure 10. Process for integrating digital forest inventory and TM satellite imagery for stand vigor update (expressed as current net volume growth).

If successful, the process will facilitate the discrimination between stands of differing volume increments. This makes the inventory data base many times more powerful and informative in supporting the design of judicious forest management strategies. Since TM imagery provides forest-wide coverage, the approach has direct operational pay offs by enabling a comprehensive update for stand vigor across the entire resource.

State of vigor is a transient characteristic and the volume increment predictions are relevant only in the short-term. Thus, the intent is to perform the TM-based update periodically at the five year intervals which correspond with the New Brunswick forest management planning cycle. The next cycle begins in January 1991 and efforts are aimed at bringing the methodology to an operational state by that date.

Summary of GIS Implications for Future Inventory Practises

The three inventory update examples cited here demonstrate substantial improvements in forest information management afforded by GIS technology. They clearly support three of the fundamental requirements of judicious forest management, namely: (1) allowing continual reconciliation of expected and actual forest performance, (2) maintenance of accurate stand descriptions with which to initialize stand development forecasts, and (3) providing a basis for evaluating the effectiveness of forest management investments.

Perhaps more importantly, the update examples reveal something about the effect of GIS technology on the future evolution of forest inventory practises. From my perspective, there are four salient implications in this regard.

1. Electronic remote sensing will replace conventional photography as the main data source for forest inventory. Already, this is becoming old news, as witnessed by the increasing use of SPOT and TM imagery and accelerated research and development of new operational sensors. MEIS imagery is particularly attractive and success in bringing it to a fully operational state will be major boon to forest management. Full capitalization on the potential of electronic remote sensing will require efficient integration of GIS and image analysis technology beyond that presently available.

2. There will be a transition from a concept of re-inventory to one of inventory revision. Typically, forest inventories go through cycles of compilation, obsolescence, and recompilation. At recompilation, the slate is wiped clean and the new inventory is prepared from scratch with new delineation of features and interpretation of their condition. Little if any information is carried forward from one inventory to the next. Updating, as illustrated by the stand diary concept, will change that. The stand diary system contains invaluable information about the resource description and it is logical that this information be passed from one inventory to the next. The result will be one of inventory revision where features in the initial inventory are retained and the conditions of all constituent stands are merely revised to reflect the cumulative effect of fast and slow changes which have occurred. This revision approach may become the norm, not only because historical information is valuable in describing the current condition, but also because digital representation of geographic features is so expensive to construct.

3. A switch from re-inventory to inventory revision extends the useful life of information by passing it along from one inventory to the next. Extending its life greatly enhances the value and utility of information and can justify increased investment in information acquisition. Thus, one can anticipate expanded inventory programs which are more sophisticated, more comprehensive, more expensive, and more accurate. These programs in turn will increase the utility of GIS in providing forest management insight through analysis of high quality resource information.

4. The traditional re-inventory practise precludes evaluation of stand development forecasts because mapped features may be geographically redefined with each new inventory. However, because management strategies are based on forecasts, rigorous evaluation of those forecasts is critical to ensure that implemented strategies attain the desired results. Inventory revision provides more permanence of geographic features and, thus, facilitates systematic reconciliation of actual and forecast stand behaviour. This creates the opportunity to assign predicted conditions to stands in the same format that current conditions are assigned. As a result forest inventories will change from merely providing current status, to explicitly defining expected future status as well. Forest management will benefit from the resultant ability to evaluate forecast accuracy, and learn from, and adapt to the findings.

I hope this paper has proven informative about the importance of updating a GIS-based forest inventory and about the mechanics of the update processes themselves. In New Brunswick, GIS management of forestry information is imperfect and incomplete and much more remains to be done. However, eight years of GIS use in forest management has clearly taught us one fundamental message: while diligent, systematic inventory updating provides no assurance of GIS success, superficial and incomplete update programs will guarantee GIS failure.

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When Do We Reach the Leading Edge of Technology?

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Abstract
This paper describes the migration of the company's GIS from a minicomputer-based system to an integrated minicomputer/workstation environment. It begins by looking at the original configuration and the woes that befell it as the demand for computing power quickly outstripped its capacity. The paper explains the review and decision-making process, examining the alternatives that were evaluated and outlining the reasons for the final decision to network engineering workstations to the existing minicomputer.

Introduction

A Geographic Information System, as with most computer systems in todays information age, never stops growing. It seems no sooner have we finished one system upgrade than our database is full, our CPU is overloaded and it is time to begin planning the next one. Until recently, increases in processing capacity meant a CPU upgrade and were almost always a major expenditure, a fact that often did not sit well with Divisional managers who have to worry about the bottom line. At MacMillan Bloedel, we were faced with the need for more computing power just two and one half years after purchasing a new system which was expected to satisfy our requirements for the next five years. Our decision to network high-performance 32 bit workstations into our minicomputer not only solved our immediate processing shortfall but also gave us the flexibility for future upgrades at a much lower incremental cost.

Background History

Before proceeding with a discussion of our journey into the world of workstations and networks, it is important to first set the stage by describing our existing minicomputer environment and how we got there. We began by computerizing our mapping in 1979 on a DEC 11/70 running Intergraph software. While the graphical side of the system was satisfactory, the analytical processing capabilities were not. Therefore, in late 1986 we converted to ARC/INFO software and PRIME hardware. Our minicomputer configuration now consists of a PRIME 9655 with 8 megabytes of memory and 2.75 gigabytes of disk storage. Attached to the PRIME are 4 Tektronix 4111 digitizing workstations, a Calcomp 5744 electrostatic plotter, a Calcomp 960 pen plotter, a 400 lpm printer and a 1600 bpi tape drive. Our database covers a landbase of 1.5 million hectares and is comprised of approximately 380 1:20 000 mapsheets. We run two shifts of digitizers, four per shift, working primarily on inventory maintenance, which is the updating of our database to reflect the previous year's logging activity. At present this accounts for our only interactive processing, all other processing and analysis is done in batch mode.

Woes Of An Overworked Minicomputer

Anyone who has planned a system upgrade knows that the final configuration is a combination of careful analysis, gut feel and budget constraints. Our 1986 system configuration was our best guess, within pre-defined financial parameters, as to the computer hardware required to handle our GIS processing. What happened to require an upgrade so soon? Quite simply, people began to use the system for more than just inventory maintenance. Analysis that was not previously possible became feasible, rerunning a scenario to see the effect of changing one variable became a practicality and data discrepancies that were previously adjusted manually were tracked down and fixed. As a result, our workload increased dramatically and we began running out of disk space, our CPU utilization jumped to 90% - 95% and our batch queues often had jobs left in them after a full weekend of uninterrupted processing. Jobs that would take 4 to 6 minutes elapsed time on a moderately loaded system were taking over an hour. Each new software release featured great enhancements but also carried the cost of an increased load on the CPU. With the growing load on the system we found we were getting further and further behind on our projects and the level of frustration amongst our digitizers was reaching an intolerable level. We realized that an upgrade was vital, and fortunately, we were able to convince our management that such was the case. However, it was made abundantly clear that this one had better last longer than two and one half years.

Upgrade Alternatives

Having been given approval in principle, we began the process of evaluating the alternatives, ever mindful of the warning, "I don't want to see you back here in two years looking for another $300,000". There were a number of criteria that had to be met: CPU power had to be increased to a level which would (1) return response time for our digitizers to an acceptable level, (2) handle batch processing requirements and (3) allow the addition of online inquiry terminals; disk capacity of the system had to be increased; and most importantly, we had to arrive at a solution with sufficient scope to avoid a major upgrade in the next five years.

Initially, we focused on a CPU upgrade, the traditional solution to a processing bottleneck. However, we were not totally confident our solution would last any longer than the previous configuration. We began exploring and expanding the possibilities around this option. It was suggested that in addition to upgrading the CPU we might replace our Tektronix 4111 graphics stations with PCs running PC ARC/INFO. In this way we would be able to transfer some of the map edit processing load to the PC thus easing the strain on the main CPU. Further discussion solidified the concept of splitting the processing load but concluded that PCs were not the best choice because of their limitations in processing power and disk storage. At this point our attention swung around to the new high performance 32 bit workstations that were becoming more prominent in the GIS field. It was obvious that we could not afford a CPU upgrade plus a set of workstations. As we learned more about their capabilities we became convinced that by networking a series of workstations with their own disk storage into the PRIME we would have ample power for our map maintenance functions on the workstations and could handle the rest of our processing requirements on the existing minicomputer CPU. All our objectives would be met with the additional benefit that future requirements for more processing power could be satisfied by adding another workstation at a much lower incremental cost than a CPU upgrade.

Design Concepts for Networked Workstations

Once we were certain that we were conceptually on the right track, we got down to the tough job of defining the details. We split this into four categories: specific processing considerations, workstation hardware specifications, network specifications, and software considerations. We began with processing concepts since decisions there would influence decisions in the other areas. However, we did find that the reverse was also true, as we became more knowledgeable about workstations and networks, we often returned to our decisions on processing flow to make refinements.

Our inventory maintenance projects are done on a management unit basis and involve working on a unit of maps (80 - 150). It was decided to transfer all the maps for a project onto the workstation disk storage where they would remain until all modifications and edits had been completed. They would then be transferred back to a pending library on the PRIME where further edit checking and summarizing would be done. Once the data had been verified as correct and signed off by the manager of the Inventory Section, it would be moved into the archive database and would replace the previous inventory for that management unit.

A number of benefits were realized by this split in processing responsibility. Each digitizer would enjoy the luxury of having a powerful computer entirely dedicated to his/her own processing requirements. The multi-tasking capability of the workstations would allow running a batch job to check one map sheet while interactively editing another. The days of complaints that someone else was hogging the system would be gone since each person would have complete control of his/her own processing destiny. The PRIME would become the custodian of the archive database, (ie., that data which had been modified, edited and signed off) and would handle all analysis and reporting functions. An added benefit of splitting the processing in this manner is that data security becomes much more straight forward. The archive database is the official copy from which all reports and analyses come, it may not be altered except in dire emergencies and then only with the written approval of the manager of the Inventory Section.

The hardware configuration phase was the one filled with the most confusion and change. It was during this phase that we first realized how elusive was the phrase "the leading edge of technology". When we began looking, the machine of our choice was rated at 3 MIPS and cost approximately $30 000. Four months later, after the dust had settled, we had chosen a 12 MIPS machine with more options for very close to the same cost. Every time we turned around there was a faster, cheaper machine available or one just on the verge of being announced. We reached the conclusion that the leading edge of technology is like the pot of gold at the end of the rainbow; you never quite get there.

Since we had no experience in dealing with networked workstations it took a while to sort through the possible combinations (eg. diskless, dataless, etc) before we were able to clearly define our requirements. We decided that we required four workstations; three would be operated by the digitizers while the fourth would be located in the systems development area and would double as a development/special projects machine and file server. In order to minimize the impact of hardware failure at any one workstation and to guarantee as much independence as possible it was decided that each workstation would have its own disk storage and would also have its own copy of the ARC/INFO software.

With this basic idea in hand, we then moved to the task of choosing specific equipment. We narrowed our choice of vendors to SUN and HP. After considerable deliberation, we decided to go with SUN for the following reasons: SUN is the development platform for ESRI which means it is the first machine to get new software releases; the majority of workstation installations of ARC/INFO are on SUN equipment; and all new SUN workstations are based on the RISC architecture. SUN's announcement of their new SPARCstations made our choice of which model to select very easy, perhaps the only easy decision in the whole hardware definition phase. We then looked at the options we wanted to add to the standard SPARCstation configuration. We replaced the standard 17" screen with a 19" screen and added the graphics accelerator option because of the high volume of graphics editing to be done. Four megabytes of additional memory were added to the existing eight megabytes to ensure there would be a minimal impact on performance by running multiple processes. For financial reasons, we chose 600 megabyte third party disk drives for each workstation except for one 327 megabyte disk drive which we purchased from SUN and attached to the development/special projects/file server machine. This was done so we would have one SUN disk to swap into a station for trouble-shooting purposes. Again to ensure workstation independence, a cartridge tape backup unit was added to each workstation so that local backups could be done.

The details of planning and configuring the network were quite simple because we completely turned the problem over to the network experts at ESRI. We simply measured the length of runs for the cable and let them take over. However once our network hardware started to arrive, we had to hook it up ourselves and were quickly educated.

Software design and development for this project has been in a constant state of change since the beginning. Knowing almost nothing about UNIX or networks when we started, we did a lot of learning and revising as we progressed. Our goal was to use the windowing and pulldown menu features of the workstations operating environment to make the user interface for the digitizers as easy as possible. Every function that a digitizer is required to perform from map editing, to retrieving and replacing maps in the map library, to backing up disk files is available on the menu system. We made a conscious effort to keep our digitizers involved to ensure that our final product was functional and met their needs. The software used for menu development and manipulation was a combination of that supplied with the workstation and the menu software used by ARC/INFO; the main work was in becoming familiar with the features and learning how to adapt them to our requirements. Many of the functions performed by the digitizers were already programmed on the PRIME so it was just a matter of converting them to the workstation and testing the results. The major software development was devoted to the map library routines. These routines perform all the functions associated with the handling of maps. They are called to transfer maps to and from the digitizers work area, to check on the status of maps, to obtain a listing of maps still to be edited, and to transfer maps to and from the archive database on the PRIME.

Implementation! This is the phase where all the plans and designs come cascading together, and if you've done a thorough job, emerge as a successful project. It is also where Murphy's law inevitably shows up at some point. Our implementation actually went quite smoothly, though there were some interesting wrinkles on the hardware acquisition side. Note the following:

1. We scheduled our SUN training for October 2 to coincide with the estimated arrival date of our first two workstations. We were dismayed at first to learn the projected shipping date was November 26 and then overjoyed when the machines actually arrived in mid-September.
2. Our first set of disk drives arrived on time but without any cables.
3. A partial shipment of our Ethernet hardware arrived with no instructions (remember we entrusted all network responsibility to ESRI). The parts list for this shipment included the box that everything was shipped in.
4. It took weeks for all our network hardware to arrive. It appeared piece by piece with the result that our network grew in spurts.
5. The initial format of our 600 megabyte disk drives yielded only 450 megabytes of useable space.
6. A tape drive was lost in space for weeks even though we had been assured more than once a week that the shipper had it in his hands and was at that moment standing on the loading dock about to hand it to the courier. When it did arrive the controller board was missing.

Training on the SUNs and UNIX for our development staff was the first item on the implementation schedule. We chose to have an instructor from SUN do in-house training as opposed to sending everyone to one of their scheduled courses in Toronto. Based on our experience, this was definitely a wise choice. We booked a meeting room at a local hotel so we wouldn't be disturbed by phone calls, etc., and had one instructor to ourselves for one week. We were able to mold the course material to our needs and focus on the topics that were most important to our particular situation. We also managed to fit in a quick course in hardware trouble-shooting when one of our SPARCstations started performing erratically.

By the time our training course had finished, the second set of workstations had arrived and we set about the task of getting everything hooked up and working. As our hardware arrived in spurts, this was an ongoing process. We were always short one cable or one connector so it took a number of weeks to finally get everything assembled and communicating. While we waited for parts, we worked on menu routines or tested assumptions we had made about the way things should work. The success of many of our processing concepts relied largely on the ability of the network to transfer volumes of data quickly. To our delight, the network performed even better than we had expected. The importing and exporting of files, required because of the different file formats between the PRIME and the SUNs, also presented no great problem though we do process them in the evening whenever possible, due to the size of our data files.

As we completed each phase of the menu development, we called on our digitizers to give the routines a thorough test and ensure they work satisfactorily. A critical component to the success of the project was the digitizers acceptance of the changes. We had no doubt the workstations were going to provide faster response time but it was equally important that the menu and windowing concepts made the operators life easier and be viewed as a change for the better.

Our project schedule began with our SUN training at the beginning of October and called for completion just before Christmas. We had planned a phased-in approach where we would convert one workstation at a time to full production. The map library routines were not completed on time but other than that our first workstation was ready for production work by the end of December. In the end, we delayed implementation until the third week in January to coincide with the start of a new inventory maintenance project.

Summary

At the end of a project, it is often useful to take a retrospective view of the proceedings, noting successes and shortcomings. In this way, we not only learn from our experiences but are also better equipped to pass on valuable information to others contemplating the same path and seeking advice. As we progressed through our review we recorded the following observations:

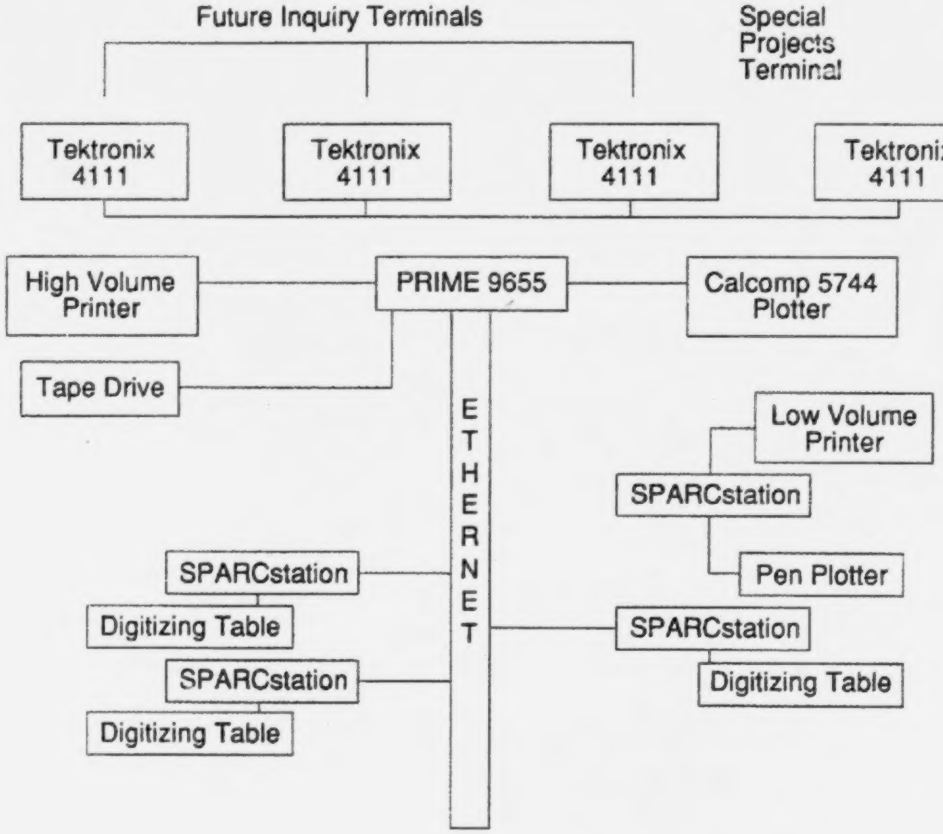
1. Since ESRI operates as a value added re-supplier (VAR), we ordered all our software and hardware through them. The advantage to this arrangement is in having one point of contact and if, as in our case, the organization chosen has the necessary expertise, it saves valuable time getting information and advice. The disadvantage is that by adding one more level of bureaucracy, the resolution of vendor problems can sometimes be more difficult.
2. It is wise to load as much disk and memory as possible into each workstation. As these commodities are reasonably cheap, it is better to err on the side of over-indulgence during the initial configuration than to face the embarrassment of going back for more money because you overlooked some item in your original design.
3. In-house training conducted far from the telephones and interruptions proved extremely successful. We estimate we gained three weeks worth of value from our one week training course.
4. Involving your users as early as possible and keeping them involved provides a sense of ownership and contributes greatly to acceptance of new concepts.
5. If the workstations are going to be used for graphics work, selecting the graphics accelerator option and the largest screen possible makes life much easier for the operators.
6. Configuring all units identically can be beneficial in trouble-shooting and also allows more flexibility in swapping machines or parts if you do have downtime on a particular unit. Additionally, setting each workstation up with its own disk and software minimizes the impact of network or file server problems.
7. The importance of building an information network cannot be over-emphasized. Through visiting other sites and

talking to people who have undertaken similar projects you gain valuable information that can end up saving a tremendous amount time on your own project.

The decision to solve our processing bottleneck by networking a series of workstations into our minicomputer instead of simply acquiring a larger CPU forced us out of our comfort zone. We had to look at new hardware, new software and most importantly, new processing concepts. The transition was not always easy. We were constantly learning, revising and, at times, struggling but with every step we became more convinced we had made the right decision. Workstations will become a major factor in computing in the 1990's. They are certainly not the answer in every processing environment but they have already stretched far beyond their original engineering role and will exert a stronger and stronger influence in traditional computing areas.

Appendix A

System Schematic



Future Inquiry Terminals
Special Projects Terminal
Tektronix 4111
Tektronix 4111
Tektronix 4111
Tektronix 4111
High Volume Printer
PRIME 9655
Calcomp 5744 Plotter
Tape Drive
ETHERNET
Low Volume Printer
SPARCstation
Pen Plotter
SPARCstation
Digitizing Table
SPARCstation
Digitizing Table
SPARCstation
Digitizing Table

SPARCstation Configuration
- internal 104 megabyte disk drives (2)
- 3 1/2" floppy disk drive
- 12 megabytes of memory
- GX accelerator
- 19" monitor
- 600 megabyte external disk drive
- external tape cartridge
- 327 megabyte external disk drive with built in tape cartridge (file server only)

Making GIS Work

Session C3
Integrated Resource Management Systems

Incorporating GISs into Decision Support Systems: Where Have We Come From and Where Do We Need To Go?

Integration of GIS and MIS

Integration Architecture and Applications

GIS'90 Symposium

Vancouver, British Columbia
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Incorporating GISs into Decision Support Systems: Where Have We Come From and Where Do We Need To Go?

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Abstract
This paper reviews some of the pitfalls in the design and use of GISs that were encountered with both large and small projects for a variety of sponsors. The standalone, self-sufficient GIS world prevalent today does not adequately meet the needs of decision support systems. Developers of these systems are left with the difficult task of software system integration which generally produces less than adequate results. Modularization of GIS concepts is critical to the solution which involves the establishment of a GIS toolkit. More functionality and flexibility are introduced through this approach so that GIS may be truly 'applied' in system development projects.

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1. Introduction

These days, geographic information systems (GISs) are being used increasingly as decision support tools throughout society in business, government, science, and academia. This widespread, practical application of GISs is a welcome, and long overdue, development. In order to ensure the continuation and efficiency of the systems use, the evolution of GISs must be based on the needs of these varied decision makers, who face an array of ever-changing, ever more complex problems. Unfortunately, this is not happening.

In our opinion, current trends in GIS development often focus too closely on technological advances; rapid changes in computer hardware, the development of new data storage and manipulation techniques, the use of new data base management software, and so on. Thus they miss the whole point of using GISs, which is to help decision makers make better decisions. A GIS is a tool for human use, not a technological end in itself; this fact is being lost too often in the heady rush of technical sophistication. We base this conclusion on twenty years of experience in developing computer-based graphical display capabilities, and even more experience in building decision support systems (DSSs) to address some very complex social and environmental problems.

To put it plainly, we believe that a GIS should be part of a decision support system, not vice versa. That is, the particular needs of the DSS should drive the design and development of a GIS, not the other way around. We do not denigrate technological improvements; on the contrary, we simply believe that they must be placed in the proper context.

These are the basic assumptions behind this paper. We will review some of the history of the development of both GISs and DSSs, and examine the impact of the microcomputer revolution of the 1980s. We will conclude with a discussion of what we consider to be the real issues and problems in building DSSs and GISs, and a view of what the future may hold for technological improvements.

2. Decision Support Systems and Spatial Analysis (GIS): A Brief History

First, we need to define what we mean by 'decision support system'. Put simply, a decision support system is any device or devices used by humans to better understand the information necessary to make a decision. This could be anything from the back of an envelope used for scribbling ideas to a sophisticated GIS running on a CRAY XMP. This simple definition recalls those once used for remote sensing technology, another spatial analysis tool which came into vogue in the 1960s and 70s. A remote sensor was defined as any device that provided information about the environment without being in actual contact with the object;, i.e., any information gatherer which could operate beyond a person's hand, hearing, or eyesight (Prentice, 1967). Despite its popularity at the time, however, remote sensing technology never quite lived up to its advertised potential. The same fate could befall DSSs and GISs, if developers fail to recognize the dangers of ignoring the human decision-making aspect of system design.

Envelopes and simple definitions aside, DSSs and GISs are most often associated with computers, because their widespread use began with the advent of the mainframe computer, the minicomputer and the desktop microcomputer. Although this is a logical association, it is not really historically accurate. For example, human beings have been using GISs for thousands of years, ever since the first person organized his thinking spatially using a map. The concept of a digital map is no different from that of an analog map. It just so happens that the digital map, when coupled with advanced computing technology, becomes a very powerful tool, and that this tool is infinitely more versatile for use in decision making than the analog.

One of the simplest and most inexpensive GISs (and DSS) is a set of spatially registered overlays, each representing various thematic data. In geography, the idea of using map overlays to study spatial covariance has been around since the availability of transparent media such as vellum and mylar, but the idea of using a multitude of overlays for spatial analysis did not catch on until the 1970s, when Ian McHarg popularized the concept of using color-coded overlays for site suitability analysis (McHarg, 1969).

McHarg, a landscape architect, taught this decision support technique to his students, who quickly adapted the technique to computers. Not coincidentally, McHarg published his popular book, ***Design with Nature***, only six months before the first Earth Day, April 22, 1970, which was initiated and managed at the University of Pennsylvania, where McHarg was a teacher. In that same year, the National Environmental Protection Act (NEPA) was passed. The map overlay technique was so simple in concept that it was quickly seized upon as an ideal tool to address many environmental problems that demanded immediate national attention. One of McHarg's students, Charles Meyer, became a consultant at Oak Ridge National Laboratory (ORNL) in 1969 and was instrumental in starting the first ORNL geographic information system, called ORRMIS (Meyers, 1971, and Durfee, 1974).

Almost at the same time as the emergence of the McHarg overlay approach, other techniques using line printer maps to create overlays began to appear in use at a number of research institutions throughout the U.S. and Europe. This technique, now considered primitive, was used largely for environmental assessment purposes, but was also applied to urban land use development and decisions concerning transportation corridors. The institutions using these techniques were also extensively involved in developing the first sophisticated environmental and land use modeling tools, which were often heavily dependent upon computer graphics for viewing both the input and output data.

It is important to note that much of the impetus for these developments in environmental modeling came from the National Science Foundation's RANN Program (Research Applied to National Needs), which awarded more than 20 million dollars in research grants to foster the development of environmental decision support models between 1970 and 1976 (Mar, 1977). Considering this unique constellation of events, Earth Day, NEPA's passage, the RANN program, McHarg's innovations, there can be no question that both GISs and DSSs were born out of the environmental crisis movement of the 1960s and 70s.

One of the best-known of the line printer mapping systems was SYMAP, developed at the Harvard Graduate School of Design, Laboratory for Computer Graphics and Spatial Analysis. Many people erroneously thought, and still think, of SYMAP as a GIS; but in fact, it was simply a low-cost graphics package. However, it ended up in many GISs developed by other research institutions and does deserve special recognition as a major milestone in the evolution of GISs technology.

The introduction of the IBM 360 in the mid-1960s represents another major milestone in the evolution of both DSSs and GISs. Without this large mainframe computer, many of the special algorithms needed to solve poorly-structured decision problems or complicated spatial analysis problems, such as polygon overlays or point in polygon determination, could not have been developed.

In the early 1970s, minicomputers began playing a prominent role in the development of GISs, mostly for specialized tasks such as digitizing. Hardware was limited, however, and software was almost nonexistent. By the mid-1970s, overall GIS development had expanded to stand-alone minicomputer systems and rudimentary workstations. Several commercial systems grew out of these developments, and image processing systems became popular with the advent of landsat data.

Today, the individual decision maker can command much of the power of the older mainframes through a desktop microcomputer workstation. As workstations gain more storage capacity and faster operating speed, an increasing number of DSS and GIS problems can be addressed directly at the user's desk. A recent review of GIS systems identified more than 50 vendors that now claim to have PC capabilities (Dobson and Parker, 1990). These developments present us with entirely new sets of opportunities and problems, and these are the main issues dealt with in this paper.

3. The Lessons Learned

Because the cost of building a GIS in the early years was so large, developers were forced to spread the investment among as many potential users as possible. Thus the potential for failure was virtually built into a system's initial design because it would have to be so large and cumbersome. In this way, many GISs failed to reach their promised potential, and earned a bad reputation with policy analysts. With the aforementioned development of powerful desktop computing, however, this situation is changing rapidly. With microcomputer technology, we can now tailor the hardware and software quite specifically to meet certain decision needs.

Despite the advantages produced by the advent of 'the personal GIS', many of the problems encountered in the mainframe computing era are still us with today, and threaten to disillusion the user as before.

The failures of the GIS experience in the 1960s and 70s, particular in the building of gigantic systems, 'dinosaurs', provide valuable lessons for present and future developments. These cautionary tales should be brought to the attention of today's young graduates as they set out to develop even more sophisticated hardware and software.

For example, the Canada Geographic Information System under development in the early 1970s was billed as a single system that would assess land capabilities for agriculture, forestry, recreation, ungulates and waterfowl, and water for sport fishing (Information Canada, Ottawa, 1973). This grand design was so all-encompassing, and ultimately so expensive, that, with hindsight, we can now see there was never any hope of completing it. The main developmental stumbling block that eventually brought down this system, and many others as well, including ORRMIS, developed at ORNL, was its inability to acquire sufficient, quality data. Clearly, one of the most important lessons to be learned from this age of the dinosaurs is not to promise more than you can deliver, and to make it clear that GISs can answer only some of the questions decision makers typically have. We have the serviceable remnants of those systems imbedded in many GISs today. But have we learned the lesson?

Past failures have also taught us to avoid shackling a system to a specific technology or software. When this happened in the past, systems were almost always overwhelmed and outdated by new technologies; in today's hyper-volatile computer environment, this possibility is even more certain, and will occur more quickly.

If DSS and GIS developers can avoid the traps of the past, then the burgeoning technology now available can serve them, and decision-makers, in ways unthinkable a few years ago. The clearest example is the rapid prototyping techniques so prevalent in data systems development today. Rapid prototyping provides a cost-efficient way to develop versions of decision support systems that precisely meet a decision-maker's needs. The decision-maker can use each successive prototype to hone his ideas and requirements more finely, while the developer uses the hands-on feedback from the user to refine the next version of the system. The process is quicker, more cost efficient, and provides a degree of interaction between decision maker and developer that could never have been achieved before the PC revolution of the 1980s.

4. Issues Confronting GIS Developers Today

The issues facing DSS and GIS developers today are not primarily technological but center around establishing guidelines or standards, promoting industry and interagency cooperation, and providing appropriate information management. Before these issues are examined further, however, it is necessary to provide a general background on how DSSs are currently developed. We believe this will underscore our view that DSSs are tools designed to help make better decisions for specific ranges of problems.

In general, DSSs heavily rely on a computational model which often requires a spatial setting or has a strong spatial component. For example, in a simple system, a DSS might have an analytical module which has an inherent spatial distribution that requires a georeference backdrop to orient the user. An air dispersion model overlain on a reference map would be an illustration of this. A more complex example is the multiple module DSS. The output from an analytical model, like air dispersion, is integrated with other analytical modules such as economic feedback and ecological impact projections. In this complex case, the implied interaction is spatially based and requires integration with spatial data and a spatial analysis system.

DSS developers view the analysis components, air dispersion, economic, and so on, as the building blocks of the system; the GIS component is the bonding agent. The coordination of these components usually takes place in a specially written program control module which may also handle the user interface system. It is not unusual for the analysis components to come from existing software developed by unrelated programmers where source code may not be available or affordable. Thus a major task of the DDS developer is that of software system integration.

Another major task is that of integrating the most vital ingredient of a DSS, information. A DSS developer must incorporate aspects of data acquisition, transformation, and management. Only those data appropriate, accessible, or affordable must be acquired. Special considerations must be given to how the data will be manipulated within the system to maintain their meaningfulness. The amount of data must be sufficient to provide worthwhile results but must also be of a volume that may be administered and suitably distributed among multiple DSSs as necessary.

In many cases, however, these admirable technological processes are not the crux of the matter. The use of DSSs and GISs for pollution control is one example. In this situation, a decision-maker's main concern might be financial, e.g., the cost of pollution control abatement equipment, or political in nature; the technology of his decision support system is of secondary significance. If a DSS or GIS is not designed with the 'human factor' as the primary concern, then the humans who make decisions will look elsewhere for support.

The major issues facing DSS developers can be summarized in two words: integration and data. Both of these issues are concerned with taking advantage of the wide proliferation of technologies and successfully applying them to complex problems ranging from site-specific questions to national or global issues. To do this, however, the developer must confront a number of challenging questions. For example, how do you:

- Incorporate complex analysis models and GIS into the DSS framework?
- Effectively integrate GIS technologies, and network multiple systems based on differing computer platforms?
- Transform the voluminous amounts of computerized thematic and spatial data, especially remotely sensed data (in the terrabytes), into meaningful information that can be used in decision support systems and environmental models developed by ecologists, planners, hydrologists, engineers, meteorologists, etc. How do you represent continuously varying soil types and characteristics as discrete digital units so that they are useful to a soil scientist, utility engineer, and regional planner?
- Use different geographic data structures between systems (e.g., rasters, vectors, quadtrees, cartographic spaghetti, networks, and the like)?
- Analyze and maintain large geographic data bases over time? Research has focused on the X- and Y- dimensions, done an inadequate job on the Z- dimension or depth plane, and has seemingly forgotten the temporal aspect.

The process is much like developing the basic ingredients needed for a military force, such as ground weapons, aircraft, vehicles, communication systems, intelligence capabilities, etc. Each performs well for its own designed function, with its own trained crew, fuel supply, information input, etc. However, success depends upon integrating these discrete elements into a unified fighting force capable of accomplishing complex missions. To do this, not only must the data needs of the various commands be met, the data must be managed efficiently, over a period of time.

Thus, the main question facing DSS and GIS developers today is this: "Can we master the tidal wave of new technology and turn it to the service of human decision-making needs, or will we go down in its flood?"

5. Where Do We Go From Here?

In the future, developers of DSSs and GISs will need to carefully consider the directions of technological change but always with an interpretive eye toward how these improvements will facilitate making better decisions. As noted above, in today's system design environment anyone who becomes locked into a particular technology or software is in grave danger of being overrun by a completely new technology. The rapid pace of technological change, where our equipment faces obsolescence every year, tends to focus our attention on ways of adapting the new technology to existing systems, rather than on ways of using it to facilitate better decision making (Machrone, 1989). Developers of DSSs as well as GISs must adopt the practice of peering into the opposite end of the telescope as well as the eyepiece used by the decision maker; he must not only see the problems faced by them, but also how the solution will affect the users. It is only by focusing on the user's decision making needs and methods of organizing their thoughts that we can employ new technology for making better decisions.

A glimpse into the future at the emerging new technologies offers some exciting possibilities to improve the lot of the decision maker. For example, one of the most promising, from a decision maker's perspective, is the incorporation of artificial intelligence into a DSS. By combining the rule-based approach of an expert system and the domain expert data capture through automated knowledge acquisition, a DSS developer can more effectively deliver a system to meet the expectations of the decision maker. A system of this type would be able to coordinate the analytical models of the DSS based on the inferences arrived at by the rule base and knowledge base supplied by actual experiences of human domain experts. Steps toward this development have already begun in terms of knowledge-based planning systems (Fiksel and Hayes-Roth, 1989).

The entire aspect of the user interface needs to be expanded to more thoroughly embrace the concept of direct manipulation. Besides trying to meet new windowing standards (X Windows, MS Windows, Presentation Manager, and so on), DSSs should strive to embrace the hypertext, hypermedia concepts for data retrieval and user-driven organization. This includes the need to integrate real-time video and digital data in a high-resolution display environment (e.g., combining thematic maps from an ecological model with video-captured data from a fly-over of the study area). These techniques are available now, but have not been implemented in a computational framework with geo-spatial analysis and feedback to both video and digital mediums.

Improvement of computational speeds and data transfer rates will undoubtedly be a boon for the high-resolution, graphics and data-intensive arena of DSSs with GIS capabilities. In this decade, we can expect commercialisation of recent technological breakthroughs such as the 16MB dynamic RAM chip, the 200 MIPS processor, the gigabit bandwidth, channel-attached supercomputer connectivity, and low-cost, add-on parallel processing capabilities for microcomputers. These advances will help DSSs make the quantum leap to speeds of human visualization. Decision support system developers need to be ready for the continuous barrage of technological improvements by lobbying for the necessary GIS integration tools.

All of these advances must have a single primary goal: to help human decision-makers make better decisions. If this is not the focus of future system design, then all of our amazing technological developments will be largely irrelevant, because they will not be used. The present level of enthusiasm among developers about the effectiveness of GISs is understandable; however, we should not let their enthusiasm lead us into grandiose advertisements of the GIS as a panacea for decision-makers. A GIS can be an extremely valuable component of many, but not all, decision support systems. It is a disservice to the GIS concept, and to decision-makers, to claim anything beyond this useful and important function.

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Effective Integration of GIS and MIS

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Abstract

Geographic Information Systems are often implemented in isolation from other information systems within an organization. This is common within the forest industry where there is no direct link or integration with the Management Information System complex. Commonly, the information held within a forestry GIS has been extremely under utilized because there has been no plan to integrate all of an organization's information systems.

Organizations are beginning to implement complete mill-wide systems from accounting to process-control to GIS. Implementation must assure that all communication and database linkages are established and in place for the operation of decision-models that integrate all of the information held within the MIS for improved management at both the forest and mill operations level and the corporate level.

1.0 Introduction

A definition of 'GIS/MIS Integration' is difficult to nail down because it seems to mean different things to different people. One common link is that the words 'GIS/MIS Integration' have connotations of large and complicated systems which seem to have little relevance to all but the largest and most advanced users. Instead of trying to come up with a very explicit definition of GIS/MIS integration, it would be more valuable to focus on the primary concept behind GIS/MIS integration which is the sharing of information. This is something to which all GIS users must be able to relate. This is especially true because of the increasing emphasis on environmental and quality of life issues which have helped to emphasize the need for integrated resource management, sustainable development and other such concepts, all of which require the sharing of information among different users from different disciplines.

Integrated resource management greatly alters the decision-making process. In order for it this process to function effectively, it requires support from both a systems and organizational level. Very simply, integrated resource management requires integrated data management. Within an organization, this means that data goes from being a departmental resource (single discipline) to a corporate (multiple discipline) resource. GIS implementation is more complex within this environment however the issues can be separated into two broad categories: communications and information flow. These apply at both the system and the organizational levels. The implementation of a GIS must be part of a complete business solution rather than just a pure technological solution. The technical solution must be supported by the proper organizational structure and operations in order for it to be used effectively. The sharing of information must occur at both these levels in order for integrated resource management to be successful. The technical and organizational concerns cannot be resolved in isolation of each other. A successful business solution will solve problems by incorporating both technical and organizational solutions.

2.0 Organizational and Technical Issues

2.1 Source Data

The preparation of a plan for operating and maintaining a GIS/MIS database must begin with an evaluation of the original source data. This is crucial because the data within the system will likely be used for purposes which it may not have been originally intended. The questions that need to be answered at this point include:

1) Does new data need to be collected?
2) Is there data that needs to be collected differently?
3) Is the data available in a timely fashion for all users?

The failure to resolve these questions will likely result in a system that simply automates an existing manual process and does not take advantage of a GIS full potential. GIS fundamentally changes the way information is managed and used. It doesn't begin with the computer, but rather ends with the computer and thus implementation should begin with the raw source data.

New users will demand new requirements of the database. This means that information may have to be collected in more detail or processed differently to store the required detail. This should most often mean modifications to the data collection design or a different interpretation of the data rather than embarking on a completely new data collection system.

An integrated system also changes the way decisions are made because it makes new data available. This data will only be able to be used if the implementation plan entails an examination of the complete data cycle from collection to reporting.

The other associated key data issue is one of timeliness. This has the potential to have a much more significant impact upon the data collection process. These impacts begin with changes to the update cycle and end up with alterations to the reporting cycle. Changes to the update cycle can be massive when a natural resource inventory database is integrated directly into the financial reporting cycle where biological management is mixed with financial management. The required changes may be so large that current data collection methodologies have to be completely rethought. This is one area where innovative technologies (remote sensing) and processes have a large role to play.

2.2 Data Redundancy

Data redundancy is a large issue when information needs to be shared among a diverse set of users. Duplicate data falls into two general categories. The first case of data redundancy involves the collection of the exact same data from the same source. This can be solved through the simple elimination of one dataset. A much more difficult, and common problem arises when the same data from different sources is collected. Over time, there has been little standardization in mapping and thus it can be expected that data from different sources will differ by location, detail, and classification depending on its intended use, age, and the collection and interpretation methodologies used. The rationalization of several data sources can be an extremely arduous and complex task.

An excellent example is a level or theme containing information about road networks. By only considering two possible users, forestry and wildlife, the conflicts can identified. The forest planner will want roads classified based on their ability to handle woods traffic while a wildlife user may want them classified based on how they open up access to valuable wildlife habitat. Roads that are no more than trails may be of no interest to the forestry user however these roads cannot open up significant new territory to hunters with all-terrain vehicles.

The rationalization of data redundancy leads to higher initial costs however it results lower operating and maintenance costs in the long-run and a more effective and responsive GIS.

2.3 Data Standards

Obviously, all GIS databases must have documented standards (data dictionary, documentation, etc.). An integrated database is no different, however the requirement for these standards needs to be emphasized because the situation will exist where users are detached from the data to which they will have access. These standards are necessary to help avoid the dangers of misapplication of the data through faulty interpretation due to an unawareness of the data's true meaning and value.

The establishment of these standards is difficult because of the diverse needs of the users. The adoption of everyone's standards into one common set of standards is the most straight forward approach however it may not be the most efficient because it falls into the category of simply copying a manual or already existing system. A review of all standards with the objective of finding some common ground will lead to a more effective solution and will also help to identify cost-savings in other areas such as data collection.

The adoption and maintenance of these standards will again assure lower long-run cost-savings but more importantly, will help assure that the system provides the right answers.

2.4 Data Control

There is only so much control that can be efficiently placed on a system by the system's built-in 'technical' mechanisms themselves. These include items such as the previously discussed data standards. It is necessary to supplement these measures with an organizational control mechanism ie: human control.

Implementation of this control mechanism can be difficult in large decentralized organizations because of the perceived potential loss of control over departmental data when it is turned into a corporate resource. Complete centralization is not a suitable answer because of the massive structural changes it can entail. Although some minor structural changes may be necessary, they should have to be implemented as a result of a changing decision-making process rather than the implementation of a new technology. One method for exercising control over an integrated system is to have a central coordinator who has enough familiarity with all of the data to assure that standards are maintained. The coordinator is a role or function rather than a position and thus may be accomplished by several individuals.

It is important to avoid too much centralization because it may result in all users becoming detached from their data, however a large degree of cooperation between different users is necessary for optimal efficiency. As much as possible, the major users of the data should exercise control over their data while taking into account the other users' needs. This 'centralized/decentralized' approach is also necessary to help avoid upsetting the corporate culture (i.e., the 'its my territory' syndrome) too much and to help maintain management and staff support. Management support and use of the system is necessary for its success.

2.5 System Management and Maintenance

The maintenance of an integrated system can be difficult because of the fears regarding loss of control as systems become a corporate resource along with the data. Networks help to alleviate this greatly however there still has to exist an overall control over the network. The networks probably give more of an illusion of decentralized control than anything. Centralized control is necessary to avoid the high costs of hardware and software duplication as well as enforcing standards for those items.

2.6 Scheduling

A major problem that can only be resolved through careful planning and the assurance that all users are communicating is scheduling. The integration of many users into one system means that everyone's priorities will have to be integrated as well. This brings us back to the issues of data collection and database maintenance. The simple approach would be to bring all of the users' schedules down to the lowest common denominator but this would likely result in a system that only collects data. Innovative technologies and planning will have to applied in order to find a compromise solution.

2.7 Financial Control

The financial management of an integrated system is more complex because shared information presumably means shared cost. Although a successfully integrated system should lead to lower costs however the costs will be more difficult to manage and maintain a decentralized organizational structure. A large benefit to this cooperative financing is that the organization is better able to afford and justify specialized capital items. Again, the answer is cooperation rather than decentralization and the coordinator will play a large role in orchestrating the system's financing.

3.0 Summary

GIS/MIS integration is best approached through implementing a complete business solution. It would seem to be pointless in trying to categorize them since all users have different needs. There are many degrees of GIS/MIS integration and its application varies upon the user and how the information will be used.

The issues discussed here are some of the major concerns that need to be addressed. Their pertinence to each user will depend upon the organization's size, structure and objectives for the system.

Whether the integration involves the integration of two similar disciplines or a complete financial/natural resource database integration the common thread is that they involve the sharing of information and the issues are the same for all users, albeit more complex for some.

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Integration Architecture and Applications

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Abstract
GIS software and standards, by themselves, can yield significant benefits through proper implementation and use by well-trained operators. Application software from modeling the impacts of alternative management actions can also provide certain benefits to certain users. However, resource management specialists generally do not have the time or inclination to become 'well-trained GIS operators,' model experts, or systems experts, nor should they have to be. Similarly, such resource management professionals should not be required to design resource analysis projects by hand and submit them to GIS operators as might have occurred ten or more years ago. In addition, to analyze many resource management alternatives, the effects of many factors must be considered simultaneously. The software and data needed for such analysis often reside on different hardware platforms in different locations, are maintained in different formats by different vendors software, and may represent altogether different technologies. To achieve true benefits in this non-integrated, complex environment for professional resource managers, a powerful integration architecture is needed. Examples of current work in the U.S. and Canada are cited.

Introduction

Traditionally, natural resource management has been accomplished by the work of skilled professionals in the field, followed by lengthy and voluminous amounts of office work spent manually drafting maps and attempting to compute the effects of alternative management scenarios. Eventually, some of that manual computational effort was reduced by the development of large numbers of independent impact assessment simulation models developed by universities or government agencies in different geographic areas to address unique problems and impacts in those areas.

Later, GIS technology and remote sensing technologies became more viable and available to resource management organizations for use in reducing the burden of manual drafting and capture of data necessary for analysis. Nevertheless, the introduction of all these various tools still did not allow the real users, i.e., the professional resource managers (foresters, resource specialists, etc.), to bring these tools to bear on real resource management problems in a substantial way.

Most of these resource management organizations still were faced with problems associated with: underpowered computer equipment from multiple vendors, lack of integration among computers and systems in the same or different locations, lack of an effective network and abilities to access data throughout the network, and lack of user-friendly abilities to use the various tools without being an expert. Since many of these resource managers moved around from time to time, the systems available were generally non-portable among machines and operating systems in the different locations. Therefore, training was an even greater problem.

The prevailing attitude in the press, conferences, and other forums seems to be that modern GIS packages along with adherence to emerging standards will effectively represent the solution for supplying the functional needs, portability requirements, and vendor independence among these resource managers.

Based on recent experience in the U.S. and Canada with natural resource agencies and a variety of commercial entities, standards have proven to be a positive factor toward achieving the resource manager's goals, but they will not solve all of the problems by themselves. Several other essential components have proven to be necessary to insulate both the users and the applications from the rest of the technical environment in order to achieve those goals. Besides adherence to standards such as POSIX, SQL, OSI, X-Windows, and others, resource management organizations in the 1990's will need to invest in at least two other components. First, they need to shift from the traditional use of COBOL and Fortran programming languages to a more portable and standardized language such as C, in which the UNIX operating system and most of the other modern utilities and third-party packages are coded and optimized. Eventually, the C language will migrate to object oriented languages such as C++. Second, these organizations need to implement a so called 'insulation layer' of service functions called a 'technical architecture.' This technical architecture software buffers the users and the applications from the rest of the environment, including the network, the operating system functions, the data base management system, the graphic user interface, etc.

The remainder of this paper will address why this technical architecture or insulation layer of software is necessary in a resource management environment.

The Process

Before addressing the problems and solutions in more detail, it is appropriate to discuss the context for the remainder of this discussion. Although many of these points are valid for other industries besides natural resource management, the natural resource management process should be described to ensure that there is a common basis for understanding. In addition, this will avoid a solely generic discussion of technical implementation problems and solutions. Although there are many detailed variations of natural resource management activities, the following points present a structured framework within which most resource management activities can be analyzed:

- Define the scope of resource management problems and analyses,
- Capture the necessary data for analysis,
- Identify alternative resource management actions to address the problem,
- Assess the impacts of each alternative management action,
- Evaluate the results of analyses and assessments,
- Report on the alternatives and conclusions,
- Make, publicize, and execute decisions (projects).

Defining the scope of the problem involves a number of activities, many of which are manual in nature, while some of which can be assisted through automation techniques such as expert systems and geographic systems (GIS). Typical activities within this overall function include:

- identifying the target location and situation relating to a problem or a desired analysis,
- stating the objectives of the problem analysis,
- publicizing or interacting with the public regarding the location, situation, and objectives,
- identifying the public issues, concerns, and opportunities through feedback from the public,
- identifying relevant legislation, management directions and other policies; establishing evaluation criteria for analyzing management actions relevant to the problem or situation, and
- recording the project scale and scope in terms of geography, time, type of problem, size, etc.

Data capture is an essential step before any automated alternative analysis or impact assessments can be performed. If the data is not already available in complete and accurate form, then significant, long lead time effort must be expended to capture the right data for the analysis.

Identification of alternative actions involves:
- identifying the range of feasible actions based on rules, guidelines, legislation, or other criteria,
- assessing the feasibility of the actions based on high level criteria,
- looking at previous or similar analyses and projects,
- developing areas of emphasis or themes, and
- identifying public-desired alternatives.

Rule-based processing is especially applicable here.

Assessing the impacts of alternative management actions involves the following general steps:
- simulating actions and predicting impacts based on past experience, historical data and cumulative effects,
- identifying similar past actions for consideration,
- defining alternative conditions and specifications, and
- generating results of impacts in graphic or tabular formats.

Generally, these impact assessments are performed using a series of mathematical simulation models, although rule-based processing is also applicable.

Alternative evaluation involves:
- synthesizing results and assigning scores and weights based on evaluation criteria,
- displaying the results versus the evaluation criteria in meaningful ways,
- comparing alternative results,
- assessing results versus the evaluation criteria, and finally,
- obtaining public input. Data base query and reporting and display tools are particularly important in this area.

Documenting and publishing decisions from this process include such reports as environmental impact statements, environmental assessments, resource management plans, decision notices, etc.

In today's environment, another frequent step in the process is responding to public appeals or protests. Automated tools are especially helpful to quickly generate the results of additional public-desired alternatives for comparing such alternatives to the decisions from the analysis process just described. Results of all analysis of alternatives should be archived for later analysis in the event of public appeals.

The Problem

As various agencies and organizations have attempted to automate the resource management process to greater degrees, many common problems have arisen. The first problem confronted is the large number of different technologies, techniques, and tools needed to support all of the various processes described in the preceding section. Following is a partial list of the tools needed to address those processes.
- Spatial functions (GIS)
- Common user interface
- Image processing of
    - Documents
    - Satellites/aerial photography
- Powerful workstations
- Networks and distributed data bases
- Standards
- Rule-based processing
- Simulation models
- Office automation and desktop publishing
- Data base queries
- MIS systems interfaces (financial, administrative)
- Applications/other systems

Each of these tools is applicable to several or potentially all of the processes described earlier. Consequently, there is a strong need for integration of multiple technologies and tools to develop any kind of integrated automation solution in the resource management environment.

Not only is integration of multiple technologies required, but integration of products from multiple vendors is becoming a necessity, both in terms of hardware and software. No one vendor markets all of the components necessary for a full, high-quality integrated solution. For example, Vector GIS, Raster GIS, Land Information Systems (LIS), AM/FM, CAD, Imaging, statistics, and office automation are some examples of necessary packages which are normally marketed by multiple vendors. Also, workstations, servers, disk storage, optical storage, and various other peripherals may come from different vendors, especially in a network environment.

To complicate matters further in this environment, most technologies are becoming obsolete within approximately two years, and even less in many cases. Consequently, integrated systems must be able to deal with rapidly changing hardware, software, and vendors.

The environment in which the necessary integration is currently taking place in industry is one of emerging standards, which will be addressed in greater detail later. In general, however, the majority of the data processing work force is not skilled in UNIX, C, X-Windows, and similar standards at this time. Therefore, it is currently relatively expensive to acquire adequate talent in this marketplace.

One of the unusual problems being encountered is vendor turnover. Many of the well-known names in software and hardware businesses have either gone out of business, been acquired, or are currently experiencing significant financial difficulties. Examples include Lotus and Ashton-Tate. Even major hardware vendors such as IBM are experiencing problems with some of their product lines (e.g., 9370s, workstations, etc.) and are undergoing reorganizations or downsizing. Candidates for mergers, acquisitions, or other consolidations of the marketplace include the GIS vendors. Some GIS vendors are experiencing difficulties staying abreast of changing technology and user demands. There may be a shake-out in that particular market, similar to the one seen recently in the hardware market.

Many prospective users and developers of integrated natural resource management systems have viewed the emergence of new standards in the computer industry as being a 'savior' which will lead them out of the morass of difficulties just described. In reality, not only are most of these standards not really 'standard' at this time, but most vendors are developing their own compliant yet proprietary implementations of these standards. UNIX, for example, differs on virtually every hardware vendor's platform. X-Windows and other standards have similar problems. To be sure, standards do aid significantly the ability to port systems from one environment to another, however, the porting can still be fairly difficult and time consuming.

One of the problems is that waves of new technology have overtaken the standards as they emerged from the sea of set-up difficulties. While some people in industry were attempting to get 052 accepted as a standard in the PC 386 environment, the 486 and numerous other faster, cheaper platforms have arrived on the scene.

Implementation of new integrated resource management systems will have a major impact on the people intended to use such systems. Recent experience indicates that training is one of the most difficult problems being faced, both because the new systems are complex and the people are geographically dispersed. The cost of taking people off their current jobs, traveling to a central training site for several multi-day sessions, and other similar problems are causing managers to fight the implementation of these systems.

With the implementation of new automated systems, many of the old personnel functions such as drafting will be replaced by a different way of accomplishing the objectives. Digitizing, satellite/aerial imagery, GIS functions, etc., assist in performing the old functions. In terms of job descriptions and career paths, if the personnel in the old positions are designated to do the new functions, then they expect to be recognized and compensated for their increased value based on additional training received and new capabilities to operate the new systems. If the proper kind of integrated user interface is not implemented over and above the GIS, office automation, and other elements of the total system, then the intended users, the professional resource managers, will not be able to use the new systems. Only the new, highly trained GIS operators will be able to use the new systems adequately.

Finally, the integrated resource management systems will not yield the intended benefits unless the issue of incomplete and inaccurate data is addressed very early in the process. The lead time required to capture, edit, and/or assemble data from geographically dispersed locations in multiple system formats is very lengthy and is difficult at best. In addition, the data is generally relatively volatile and the expense of continuing update is enormous. In many cases, even an aggressive update frequency using traditional technologies is not adequate and field users continue to use manual systems to account for shorter term changes on the ground. Ultimately, new update techniques based on satellite and aerial imagery appear to be a necessity.

The Solution

Question: What if there were a way to buffer the resource management users and their applications from the various vendor products and complexities associated with each, from proprietary yet compliant vendor hardware and system software environments, from emerging and changing standards and technology, from the various data bases residing in any location in the network, from the network itself, and to provide an environment in which third-party packages could operate with a common user interface alongside other applications and tools?

If all of those system components could be buffered from one another in order to achieve a high degree of portability, flexibility, maintainability, independence from vendors, and similar benefits, then the chances for success of the integrated resource management system would be greatly enhanced. Based on recent experience in a number of agencies and companies, both within resource management and other industries, a proven solution has evolved. Basically, the solution involves developing and implementing a series of 'insulation software layers' between the applications,the graphic user interface (GUI), the various DBMS, files, and memory, the network services, the third-party application packages, and the operating systems function. This type of insulation layering has been implemented recently on the factory floor to integrate everything from robots, vision systems, manufacturing systems, cell controllers, and numerous other devices and software packages. It has been implemented in retail, healthcare, and other environments. It is currently being implemented in resource management and GIS environments and in a number of large integrated system environments involving image processing, traditional data processing, workstations, etc. This layered insulation or integration software can be divided into five major categories:

- Network access layer: Isolates applications from network services such as task to task communications and file transfers,
- Operating system access layer: Protects applications from directly requesting an operating systems function. Usually implemented as a function library,
- Data access layer: Allows applications to access shared memory, sequential files or multiple DBMS via a uniform method,
- User interface access layer: Insulates applications from low level calls using the user interface protocol, and
- Third-party application package access layers: One per third-party package. Serves as an interface between the application and the package so that the package is invoked like any other custom application from the perspective of both the developer and user.

These layers communicate between each other and with custom applications through an additional layer called distributed access services. This layer is the center piece of the integration architecture solution to the problems discussed earlier. This layer is aware of what is running where, the resources required, and who controls what resources. The combination of these layers leads to a highly distributed environment capable of supporting a variety of vendors on a wide range of platforms. For further details regarding this technical architecture and environment, see Ballengee, (1990).

Benefits

Benefits of this approach include greatly enhanced portability, ease of training, flexibility in dealing with changes in technology, enhanced maintainability of application systems and reduced costs, independence from vendor's proprietary but standards-compliant products, ability to operate in a highly distributed environment, and seamless integration among third-party and other products under one common user interface.

Potential Applications

While this integration architecture concept and software have been implemented in a number of industries, it is only now under consideration for implementation in the natural resource environment. Two specific projects currently under way are deemed by this author to be examples where this concept could be effectively employed. They are described briefly in the following paragraphs and should be viewed as possible applications for these concepts rather than implementations at this time.

In the U.S., the USDA Forest Service is currently in the process of procuring new platforms upon which the ideas described in this paper could be implemented. The Forest Service is purchasing UNIX type workstations, GIS software, office automation software, data base management software, etc. Meanwhile, in the field locations, various Forest Service groups are positioning themselves to take advantage of those new platforms. One such group is the Forest Pest Management (FPM) group. In conjunction with several other Forest Service groups, they have developed several integrated Forest Resource Management System (INFORMS) prototypes (Loh, 1988). While initially targeted for implementation in FPM, these systems are equally applicable to any other discipline within the Forest Service. Rule-bases, models, and other aspects of the system would differ, but the system is really an overall problem solving structure for integrating tools independently of the tools themselves. Forest Service personnel envisage an integrated system in which special functions will be available at any time for use in defining the scope of the problem, analyzing impacts of alternative management scenarios, and performing other functions. Similarly, simulation models, rule-based processing, office automation, and other necessary functions will be available at any time in a seamless environment for the purposes of problem solving and planning in an integrated environment. For further details, see Weldon, Randy M., W.B. White, et al, (1989). The use of this system will only differ depending on the perspective of the user and the discipline in which that user works, such as Forest Pest Management, Timber Planning, Inventory Analysis, Fire Protection, Range Management, etc. User and problem profiles would be maintained for subsequent use, thereby maintaining the knowledge built into each problem analysis.

The British Columbia Ministry of Forestry has implemented a number of GIS pilot sites in district offices. At the moment, most personnel are using the system to focus on data capture and updating, but some use has begun, in combination with manual procedures, to accomplish resource management and analysis functions. Automation of these functions and the solution of the problems noted in this paper would be greatly enhanced and facilitated through the use of the technical integration architecture. For further details, see Holley, Weldon, and. Mullins, (1989), and Dellert, (1989).

Conclusion

To address all of the various resource management activities and processes described here, new integrated systems and technologies are necessary. However, there are many problems and difficulties in developing and implementing such solutions. The solution to most problems lies in the development of a modern technical systems integration architecture software to buffer the users and the applications from the network, the operating systems, the data base management systems, and other elements of the systems environment. When such software is implemented, results include greatly enhanced portability, application longevity and maintainability, reduced training and maintenance costs, increased flexibility to deal with changing technology and proprietary vendor implementations of 'standards'.

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Making GIS Work

Session C5
How We Share the Data

Environmental Assessments and GIS

A Customized Interface to Access Digital Map and Forest Inventory Data

Using a Distributed GIS Database in Forest Planning

GIS '90 Symposium

Vancouver, British Columbia
March 1990

Environmental Assessments and GIS

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Abstract Georeferenced data used in environmental impact analysis comes from many sources: satellite images, digital maps, paper maps and hand-drawn sketches. In this electronic world, a GIS can perform two valuable functions: first, it is an effective tool to manage and organize the data; second, it allows quite elaborate analysis of the relationships in and between map layers.

Working with a major client, Acentech has developed a first generation environmental assessment system for use by field personnel who are neither primarily geographers nor environmentalists. Although map development tools are available, the emphasis is on the analytical processes, not cartography.

Raster-based GIS (GRASS) was chosen because it is somewhat more efficient for the purpose at hand.

The substantial non-georeferenced data (eg. animal behaviour patterns, indexes to scientific literature) are stored in the SQL-based RDBMS, Oracle. The standard user interfaces for both systems remain available to the expert users, but are invisible to the target users. A set of screens that use terminology and concepts familiar to operations personnel are provided for day-to-day use.

Software was developed to predict environmental effects and responses for the range of possible disturbances.

To enable most of the GIS and RDBMS machinery to be transparent to the end user, a module that keeps track of all map layers, whether loaded externally or generated as part of the analysis, and the analysis for which they are suitable was also developed.

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A Customized Interface to Access Digital Map and Forest Inventory Data

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Abstract
Boise Cascade Corporation has developed a customized menu-driven query and mapping system to access digital map and forest inventory data. The system provides a user interface which brings the power and capabilities of database queries and data visualization to on-the-ground field foresters, where it can best influence forest management decisions. The paper details development strategy and outlines criteria used to successfully produce a custom system appropriate for novice GIS users.

Introduction

Boise Cascade manages six million acres of owned and controlled timberlands in the U.S. and Canada. Throughout the past decade our dependency on computers and digital data to support forest management has grown steadily. The forestry information system includes geographic digital data for ownership, surface water, transportation networks, public land survey and timber stand boundaries. A corresponding inventory database contains stand characteristics, which include approximately 200 individual stand descriptors. Providing easy access and supplying current accurate information to our forest managers allows Boise Cascade to remain competitive by making more informed decisions in daily management activities. It has become increasingly important to provide field foresters with the ability to access the data and software to obtain information in an easy and efficient manner. Providing easy access to our data for part-time software users is a growing challenge as the mapping software evolves and becomes more and more complex each year. For the majority of the foresters, using mapping software is an occasional occurrence. The realization that this type of infrequent user cannot keep up-to-date and be proficient using several hundred GIS software commands led Boise Cascade to the decision to develop a user-friendly front end to support mapping and database reporting functions. The goal of the development is to transfer the operational task of producing maps and reports from analyst/programmers to field foresters. Boise Cascade believes that putting the power of GIS software in the hands of operational forest managers will improve the effective utilization of the investment in digital geographic data and supporting inventory information.

This paper reviews the rationale that motivated the development, assessment of functional needs, and steps to development and implementation of the Query System. Boise Cascade is a multi-national corporation which utilizes a decentralized organizational structure. The corporation headquarters located in Boise, Idaho has a small staff to support informational services including GIS for numerous regional offices located in six U.S. states and Canada. These regional forestry operations are autonomous and have a variety of minicomputer and PC hardware platforms to support informational services. During the mid-80's Boise Cascade made a GIS software conversion and currently uses *ARC/INFO for mapping and analysis to facilitate timberland management operations.

Development Rationale

The ultimate objective was to design and develop a menu-driven Query System to facilitate the production of quality map and report products using easy and efficient procedures. The development of this front end system limits the scope of the software by focusing only on necessary capabilities to produce standard informational products that support timberland management. The benefits of focusing software functions is derived by decreasing software training costs for forestry personnel. The system is projected to increase returns to Boise Cascade by greatly broadening the range of people able to use the system to include both novice and expert GIS users. An additional benefit which is hard to quantify is the increased acceptability of GIS by new users due to the fact they can produce high quality map and report products in a very short amount of time with no formal ARC/INFO training.

By providing an operating framework for users, the system can eliminate many common sources of errors through consistently organized procedures. By controlling the software environment, the Query System allows for consistent products that meet desired standards for symbologies and map feature composition.

Needs Assessment

It was clear from the inception that development had to focus on the capabilities of the system to meet the end users' needs. To move beyond an idea, it was necessary to identify and describe proposed product expectations. Furthermore, if the product was to be developed with the end user in mind, the attributes of intended users needed to be defined. This examination concluded that end users were professional foresters of all ages with various levels of computer experience and background that ranged from non-users to very knowledgeable users. By the nature of their responsibilities, the majority of them were rainy-day users. Therefore, the first system requirement was that the system be easy to learn and use. To support this requirement the system needed to be menu-driven, which supports a lower level of software knowledge than command driven applications. This idea is supported by our past experience of introducing personal computer systems throughout forestry operations. In that experience, *Apple Macintosh personal computers were more widely accepted by our users because they utilized a graphic interface. During the past five years, this fact has proven to be true time and time again. The majority of users are more comfortable and productive in a point-and-click environment which is oriented directly at the user.

Experience implementing various forestry related software applications and management tools taught Boise Cascade that users set a high priority on producing products and a very low priority on management of computer workspaces. This phenomenon can probably be attributed to the fact that office time is very limited and is usually used in preparation for or support of some field activity. Therefore, the second system requirement of the Query System would be the ability to manage the user workspace. For example, plot files sent to plotters are deleted upon completion of the plot to avoid space constraints from growing into operational problems.

Another requirement was that the Query System be developed to use a parameter file. The parameter file would be used to set up the query session environment and control defaults for plotter name, plotter size, pen configurations, printer name, tape drive names and pathnames for file

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* ARC/INFO is a trademark of Environmental Systems Research Institute.

* Apple Macintosh is a trademark of Apple Computers.

directories. The use of the parameter file in the system design provides the flexibility required to support numerous regional hardware configurations and changing hardware at individual locations over time.

To protect the data from unintentional accidents and data corruption, the system includes read only access to the data for the end user.

Furthermore, the system needed to provide the option to see plots before plotting. This visualization of query results helps reduce waste of expensive plotting supplies and system resources when users produce undesired query results. A review of field operations showed that quite often the map products produced from the Query System were required to work in concert with other products in operational use like aerial photos, orthophotoquads and other existing map products. To facilitate this use the Query System provides the user with the option to choose from a variety of map scales for the graphic output. Due to plotter size constraints at many Boise Cascade locations, a 'best-fit' option based on the specified hardware parameters was developed.

Map symbology sets are scale-dependent, based on the selected map scale to ensure compliance to cartographic design standards. Pre-designed map legends are assigned, based on selected products. The option to place legend at the top, bottom, left or right of the map is a user's choice.

To support inventory data queries and reports, the Query System was designed to handle up to five external *INFO data files. The system provides the ability to make ARCPLOT queries on items within the related inventory database.

To provide the most easy access for the lowest-level user, the system provides the ability to select one of the 10 predefined standard map queries or INFO reports. This allows users to obtain information and generate map products without creating or performing a custom query. This design feature permits fast retrieval to very specific standard queries. An example of a standard query would be a request for a township map showing ownership, roads, streams and forest stands. Another example would request a five year logging plan map and corresponding log job characteristics report. The system provides a 'custom query' selection that allows for searches of potential relationships of items located in the inventory database. Forms menus enable the user to specify conditions for the data query and produce a map depicting data for the chosen set of attributes.

Options to display to screen, to be sent to a default file, or to be sent to an export directory are available for plot files. The systems also supports options to list, purge, save, and load map creation specifications.

System Development
The task of programming and prototyping the Query System was contracted to professional software consultants at ESRI's Northwest regional office in Olympia, Washington. The Olympia staff offered the advantage of having acquired knowledge of Boise Cascade operations from earlier development efforts. Meetings were held to discuss functional requirements, design specifications and work plan time frames.

One detail that should not be overlooked when planning a development effort is the time and effort required to develop an acceptable contract that meets the needs of both client and vendor. Contract creation and acceptance of legal terms required many hours with attorneys over several months. A good contract must contain clauses that address several key issues including the right to discontinue, compensation, proprietary results and penalties for non-conformance.

The work plan should furnish several opportunities for the client to review product development and to allow for feedback to software consultants. The final step in a work plan should require the consultant to deliver and install the product and to prove required capabilities outlined in the design specifications.

Upon completion of product, the Query System was tested by GIS support staff to identify any operational bugs and to identify potential enhancements. Thorough testing is essential to the successful implementation and acceptability of new software applications.

Conclusion
The development of a customized Query System by Boise Cascade facilitates increased use of digital map and inventory data by forestry users. The system taps the potential of GIS software by providing an easy to use menu-driven interface that offers options to choose from standard pre-defined products or the capability to create custom data selections. By packaging the mapping and reporting software capabilities into a point-and-click environment, users training costs are reduced and acceptability of GIS as a management tool is greatly enhanced. Improved access to the data and the ability to easily produce quality map and report products to support forest management decisions provides Boise Cascade with increased returns from the investment in forestry information systems.

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* INFO is a trademark of HENCO Software, Inc.

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Using a Distributed GIS Database in Forest Planning

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Abstract
An integrated resource information system supported by GIS technology is being used by the U.S. Forest Service in Alaska. The system is composed of four hardware/software systems located throughout a 6.9 million hectare forest. Three administrative Areas acquire and maintain their own data bases according to Region-wide standards. The data is used locally within each of the three administrative Areas and by a central planning team. Data is extracted from each of the Area data bases and consolidated by the planning team to develop a comprehensive forest plan for the entire forest. Standardization of information structure, data elements, and data base design has resulted in the ability to obtain common views of the natural resource condition across all units, while local Area managers retain responsibility for the data on their respective Areas.

Introduction

Situation

The 6.9 million hectare Tongass National Forest is located in coastal southeast Alaska. This temperate, coastal rain forest is composed of many islands and peninsulas with intervening bodies of saltwater. Land forms include tidelands, uplifted benches, steep mountain slopes, glaciated valleys draining into deep fjords, and numerous active glaciers. Vegetation varies from the beach grasses of the intertidal area to predominantly spruce-hemlock forests and alpine tundra.

The Tongass is administered by the Alaska Region, United States Department of Agriculture, Forest Service, for a variety of goods and services. Managed under multiple-use and sustained-yield principals, the forest annually produces 1.5 million cubic meters of wood fiber, 5400 metric tons of anadromous fish, and provides 2.8 million visitor-days of recreation experiences. The forest supports a large and diverse wildlife population, including brown bears, eagles, and five species of salmon. The forest contains major deposits of gold, molybdenum, and silver that are now being explored and mined. About one-third of the Tongass is in 14 legislated wilderness areas totaling 2.2 million hectares.

The large size of the Tongass necessitated dividing it into three administrative Areas averaging 2.3 million hectares with each headquarter offices in Sitka, Petersburg, and Ketchikan, Alaska. Each Area is administered by a Forest Supervisor with a staff of natural resource and technical specialists, and up to five District Rangers who are responsible for field operations on their assigned portion of the Area. An inter-disciplinary planning team, charged with integrated land management planning for the entire forest, works under the direction of the three Forest Supervisors. The team is located in Juneau, Alaska.

Since 1979, the Tongass has been managed according to an integrated forest land management plan, known as the Tongass Land Management Plan. The plan makes general land use allocations and establishes guidelines for site-specific resource development activities. This plan is being revised to meet new and emerging issues and concerns. The management direction set by the plan revision must respond to considerable public concerns, legislation, and ensure continued productivity of the land and natural resources of the forest.

Management of the Tongass has attracted the interest and concern of people across the United States. Considerable debate is taking place locally and in the halls of the United States Congress on how the Tongass should be managed.

Within this context, the Regional leadership team decided to use a distributed Geographic Information System (GIS) as a decision support tool for managing the vast amounts of data necessary to prepare the Tongass Forest Land Management Plan revision.

Supporting Technology

A distributed integrated resource information system (IRIS) has been developed with portions of the data base residing at each Area Office. The IRIS data base resides on three separate Forest Service-owned Data General MV series minicomputers, linked together by DEPNET, the U.S. Department of Agriculture's wide-area telecommunications network. Computers located at each of the Area Supervisor's headquarters support a full range of office automation and data processing, in addition to the integrated resource information system. The central planning team is supported by the Regional Office computer located in Juneau, Alaska, and is linked to the others by DEPNET.

The IRIS uses Environmental Systems Research Institute's ARC/INFO GIS software and Oracle Corps ORACLE data base software. Data is collected and stored in ARC/INFO and analyzed through either ARC/INFO or ORACLE as the needs of the analyst dictate. Spatial analysis is done in ARC/INFO and attribute analysis is done with both ARC/INFO and ORACLE.

(Product names are used solely for clarification and do not constitute endorsement by either the author or the U.S. Forest Service.)

Developing the Integrated Resource Information System

The Tongass NF began developing an integrated resource information system supported by GIS technology in July of 1987. Today the system is operational on the three Tongass Areas. It supports local project level work such as timber sale preparation, transportation system planning, and subsistence use analysis, as well as the strategic planning work of revising the Tongass National Forest Land Management Plan.

Information and Data Management

The computer hardware and telecommunication network were already in place; thus, the management of information and data provided the greatest challenge to implementing the IRIS. The Regional leadership team used strategic data planning methods to develop the desired system. The need for significant involvement by managers and the Regional Forester was also recognized. This resulted in Regional policy requiring Regional Forester approval for the initial logical information and data structure, along with subsequent changes. Authority for physical data base design was limited to the Regional Director for Management Services. This has assured common information and data structure throughout the Alaska Region and the Tongass National Forest.

Management concern about the potential for collection of more data than was necessary resulted in a data approval process developed to control data collection. Only line officers may approve requests for new data elements to be added to the data dictionary and the data base. Two different approvals are involved. One approval is required to establish a field in the data structure and in the data dictionary for the data. A second approval is required to collect and store the data. The mere existence of a data field does not justify the universal collection of a data element.

The planning team proposes additional data elements in response to new issues. These proposals must be approved by all three Area Supervisors. Proposals that affect Regional data structure are forwarded to the Regional Forester for approval. Approved data elements are forwarded to the Regional Data Administrator for inclusion in the data dictionary.

Responsibility for data integrity rests with the local line officer managing their portion of the data base. Area Supervisors are responsible for data collection, management, currency, integrity, and adherence to standards on their respective portions of the forest.

Strategic Data Planning

Using strategic data planning methods, an information architecture has been developed which is unique to the Alaska Region. This architecture was developed in close coordination with the Forest Service national office and closely follows the evolving information standards being developed for Service-wide implementation of GIS. Intensive information needs analysis were conducted to determine what information was necessary to develop the plan revision and what data was required to obtain that information.

Information and data elements were analyzed through a data decomposition process to identify the lowest common denomination of data elements. This process resulted in the recognition of two types of data necessary for the IRIS: basic data and interpreted data. Basic data represents measurable attributes of the forest and is usually the lowest common denomination of data elements. Specific, measurable attributes of a tree are an example of basic data. Interpreted data represents aggregates of measurable (basic) data with or without further interpretation. The general attributes of a group of trees is an example of interpreted data. Most management and planning decisions are made on interpreted data. However, the parameters for each interpretation frequently change as social, economic, or political issues change. The Region's ultimate objective is to primarily store basic information and use the technology to develop all interpreted views of the data. Much of the available information and data includes interpretation and, therefore, managers have elected to include much of this in the data base to meet immediate requirements. Managers, data users, and data management consultants participated in this data planning effort.

The strategic data planning effort resulted in a standardized information architecture and data base design for the entire Region. The architecture contains the following themes: soil, terrain features, vegetation, ownership, hydrology, wildlife habitat, transportation, recreation, minerals, and cultural features. Each of these contains specific data elements.

These themes represent the data needed to develop the revised forest plan and to implement the plan through site-specific resource management projects. The data base currently is 3.4 Gb in size and is expected to expand as additional data is added for project implementation.

Distributed Database Design

The data base is geographically distributed to each of the three Area Offices. Each Area Supervisor is responsible for acquiring and maintaining data for their area of geographic responsibility.

A single data dictionary is used on all units and is managed and updated by the Regional Data Administrator. This ensures commonalty of data and the resulting views of information. Each Area may supplement the data structure with data unique to their Area as long as it conforms to the Regional data standards. This tightly-controlled data management process enables data from all three Areas of the forest to be combined into a single data base used by the planning team.

Data Standards

Standardization of all parts of the integrated resource information system is crucial to the success of this operation. The data structure is standardized and controlled through a single data dictionary and a Regional Data Administrator.

A common naming convention for drawers, folders, and files has been established across all units. This simplifies the movement of data files between the different parts of the distributed data base and the planning team's analysis data base.

Data is organized across the forest by U.S. Geologic Survey 15' Quadrangles (quads). Each quad is considered a tile and all point, line, polygon, and attribute files are registered to a quad. Each tile is given a unique name by the Regional Data Administrator. This is especially important because two Areas frequently have data on one tile.

Using the Distributed Database

The planning team in Juneau combines data from each Tongass Area to develop a comprehensive view of the forest into a planning data base. The planning team retrieves only those portions of the data needed for their current work. As new analysis activities are conducted, new data sets are retrieved from the Areas and incorporated into the planning data base.

Complete copies of attribute and spatial data are retrieved and stored for those data themes the planning team frequently uses on a forest-wide basis and require site-specific precision. Shore line, property boundaries, and transportation systems are examples of these.

Sample data sets are retrieved for those themes where planners do not need site-specific precision. Project level inventories, data analysis, and their resulting map overlay products are exceedingly complex and require major commitments of CPU, memory, and disk storage space to process. Since forest level planning does not require this level of spatial accuracy or precision, the project level inventories are statistically sampled. The sampling scheme is, by design, geo-referenced and, therefore, facilitates later project implementation.

Sampling the polygon inventories reduces their complex topology into a grid cell format. The complicated mathematical descriptions of polygons are reduced into pairs of x- and y- coordinates associated with sample points. The grid format process is efficient and easily updated.

Data samples for each theme are taken at 275-meter intervals using a common Thiessen (hexagonal) grid template for all data themes on all Areas. This template results in a grid cell of approximately 7.6 hectares. A sample size range was plotted against reliability of the data set. As expected, the smaller the sample interval, the greater the reliability. However, areas smaller than 7.6 hectares showed only marginal improved accuracy in relation to the analytical needs and the decisions being made. The grid sample brings both spatial and attribute data to the planning data base. The sample data's precise point of origin can be retraced for project implementation. The grid samples are seen as hexagonal cells on maps generated from this data.

Standard and point sample files are retrieved from the distributed data base using an identical process. The teams systems analyst uses Data General's remote retrieval process, known as RIS, which operates over the wide-area telecommunication network. Using a menu-driven process, the analyst calls the remote host, which is housing the desired files, and identifies the drawer, folder, and object to be retrieved. The receiving drawer and folder are identified on the Regional Office computer and the command is executed. Depending on the size of the file, transfer takes from 30 to 60 minutes.

A quality control check is then made by the analyst. Transmission quality is assumed due to the X.25 packet transmission process. Either a file arrives or it does not. The quality of the file is checked as a further verification on data integrity. This quality check is important because the forest is in the early stages of building the data base and occasional errors in the data are still being found. Vegetation in the middle of a lake is an example of these errors. The Area responsible for the bad file is notified of the problem and is requested to correct it within a given period of time. This is in keeping with the operating principles that data integrity lies with the owner of the data. Upon correction, the specific file is again retrieved.

Conclusions

This project has demonstrated the feasibility of using GIS in a distributed operating environment. The project's success is based on several key activities. First, the application of sound, strategic, data planning principles. The need to standardize information structures, data elements, and data base design across several organizational units requires the use of strategic data planning methodologies. Second, the commitment and involvement of managers and executives who recognize the importance of information management to the accomplishment of their objectives. A large, geographically-dispersed organization has numerous subentities which will each have their own, often conflicting, information and data needs. Resolving these differences into a common information structure and data base design requires the involvement and commitment of senior managers. Thirdly, a willingness to innovate and persevere on the part of the many people working to develop the system is crucial to successfully developing a distributed, integrated GIS-based information system.

The availability of the distributed integrated resource information data base has changed the way forest land planners approach their work. The IRIS provides an opportunity for all natural resource analysts involved in developing the plan to work with the same set of data and to readily use data from resource disciplines other than their own. This, in turn, has greatly facilitated true, inter-disciplinary discussion and analysis. In the past, this has been very difficult because each resource discipline used their own data and others had little or no access to the data. Based on the physical parameters, the planning alternatives can now be developed, flow-charted, programmed, and the results displayed on maps and attribute tables which represent relatively unbiased results. Previously, it was very difficult to analyze alternatives in an unbiased manner because one had to think about the data available to develop the alternative.

The development of the distributed integrated resource information system has greatly increased the Region's capability to use and analyze data. The system is costly, but less costly than the old methods of using separate data sets operating on many different computer systems.

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Making GIS Work

Session C6
Building (GIS) Castles in the Air

A Chicken in Every Pot...and a GIS on Every Desk

The Corporate GIS Database in a Forestry Environment

GIS in a Networking Environment

GIS'90 Symposium

Vancouver, British Columbia
March 1990

A Chicken in Every Pot ... and a GIS on Every Desk

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Abstract
The Province of British Columbia is currently involved with the design and implementation of a Corporate GIS which will be accessible to every work group throughout the resource sectors of Government. This implies a level of connectivity which, typically, is not available today. As local and wide area networks become implemented, GIS must be designed to take advantage of the emerging technologies. This paper investigates key issues such as: interfacing to heterogeneous databases, hardware and operating system independence, and data storage and transfer. Opposing philosophies of communications network configurations are compared.

Introduction

Geographic Information Systems are moving into the realm of office automation and, as such, are becoming standard tools for the management and administration of land information. Just as word processing software has evolved from the large specialized systems into the decentralized personal computer tools, so too will GIS become part of the administrators' and scientists' toolkit. However, GIS has one requirement which is radically different from other computer tools: it requires data which is standardized and which uses the same geo-referencing system for every person referencing the geographic region. This baseline data is voluminous, expensive, and scale-dependent.

The baseline data, which includes topographic data, cadastre, and general thematic descriptions, is relatively static information from which to reference other, more specialized information. The specialized information, or business information, is often most important to one agency, usually the agency of collection, but is often required by other agencies or programs. The business data is rarely static and most often managed by the agency of collection.

Providing both baseline and business data for individuals is difficult to manage. The essence of the problem is the sharing of this data. Data sharing, temporally or physically, is not limited to baseline data. A single agency manages many data sets which must be shared and are shared via electronic communications, paper forms and reports, or by communication between individuals using the data. The utility of GIS, however, can only be realized if the data can be shared via electronic communications networks. The current requirement for broad access to GIS functionality is the coupling of GIS, database technology, and communications architectures.

Communications networks and data transfer protocols are not new. The field is well-developed and extensive systems exist which handle great volumes of data at rapid transfer rates. GIS systems require data from many sources and broad access to these systems implies the utilization of data from disparate database management systems. In the most general case, large-scale access to GIS functionality means the interaction of many different GIS systems operating on a variety of hardware platforms. The problem of developing a communications network which can move data from any DBMS and any GIS to any other has not been solved, and must be, to bring GIS into the world of office automation.

The Province of British Columbia is building a Corporate GIS infrastructure to provide GIS capabilities to every agency in every ministry in every region. The world of complete connectivity and uniform geo-referencing is a long way off, but it is both logically and technologically possible. This paper describes just what is required logically to create this new world and provides a framework for dealing with the implementation of the technology.

GIS Access

'A GIS on Every Desk' means access to geo-referencing tools by every member of an agency. While the needs of each user will vary, in the extreme, every user may require a full-featured GIS with graphical input/output, update capability, multiple layering, region buffering, etc. Like office automation tools, access to a GIS does not immediately imply any level of connectivity; word processors are accessible to many users, but they require no communication network or data interchange capability. However, the utility of GIS is bases upon two key links, the identification of geographic features referenced to baseline data and the identification of attributes - business information - for specific geographic features. These links require data which is optimally shared between users and between agencies. Efficient use and management of this data implies connectivity between users.

Access to a GIS can be provided by linking each user to a single computer, a mainframe or a minicomputer, running one GIS, or by providing each user with an independent CPU and GIS executable program, or some combination of the two. The actual network configuration, i.e., the electronic connections between the computers, should be transparent to the user. However, the implications of the network configuration may be extensive. If a network revolves around a central computer, users may not be able to choose software which is tailored to their needs. However, a network which is flexible enough to allow some user-independence may incur some penalties in performance, such as data conversion requirements. The network configuration also determines whether some activities can be executed in parallel or whether the computer power has to be shared. Finally, the management of data will be greatly impacted by the network configuration and the location of data storage. Performance, flexibility, and system management all factor into the design of a system which provides access in a practical way.

Webster (1988) describes a number of systems which provide GIS access given a common hardware/software platform. Data sharing is contingent on the common software implemented. However, a network of autonomous GIS nodes provides the ability to distribute both computing requirements and data management responsibilities and permits each user to have a system which is tailored to their needs. Such a system of interlinked yet autonomous computers not only permits access to GIS functions, but matches the needs of users to GIS functions. This flexibility and complete matching of user requirements to local system characteristics incurs costs which, in the short term, may make such a system prohibitive. In the long term, however, such a system should be the target.

Logical vs Technological Requirements

There are two types of problems which prevent systems engineers from designing and implementing specific systems: logical and technological. Logical problems are those problems which, when reduced to their most basic terms, reveal a conceptual inconsistency, a falsehood, a contradiction of the laws of physics or mathematics. Technological problems are those which involve an incremental and continuous change in a design parameter for their solution. Being in Vancouver and Victoria at the same time is a logical problem, travelling between the two cities within 30 minutes is a technological problem. Logical problems cannot be overcome by technological solutions, but often we can alter the problem to permit a technological solution. Technological problems may be just as difficult as logical problems, perhaps even more so, since there is no way of knowing that no solution is possible. There is a region of ambiguity between logical problems and technological problems, particularly where the 'laws' of physics are involved. Those problems which appeared to be logical ones a century ago (e.g., the concept of semiconductors) are now technological ones, shifted by means of a change in paradigm or simply by a new discovery.

Common Conceptual Data Model

The logical/technological distinction is valuable for this discussion of GIS networks because it reveals which problems require a management decision and which require scientific work. While a decision may obviate the need for scientific investigation, the converse is almost never true. GIS systems vary greatly with respect to data storage and presentation. Sharing data amongst disparate systems requires the transformation of data in form and format. Transforming data requires knowledge of the definition of each geographic entity and the ability to describe the data by some common set of building blocks. The ability to transform data between GIS systems is a logical problem: there is no certainty that the concepts inherent in one GIS can be described in another. A GIS which handles only 2-dimensional data can not transform its data into 3-dimensional data. There is a technological problem associated with transforming data which is the speed at which such a transformation can take place. There may be logical limits on the speed of transformation, given the velocity of electromagnetic waves and the energy flux, but in general, the practicality of data transformation is one that changes with the state-of-the-art. Of course, no matter how fast your translation code executes, it won't be able to transform that 2-D data into 3-D.

For the business or attribute databases, the Relational Model (Gardarin, 1989) provides a consistent model for the exchange of data between nodes in a corporate network. Structured Query Language (SQL) can be used as the protocol for communicating between databases. Geographic data is not commonly managed in a relational paradigm. In fact, no accepted conceptual model exists for geographic or geometric data. Without a consistent conceptual model, no standard access method can be applied to differing GIS.

The adoption of an underlying conceptual model for geographic data presents a logical problem for data transformation. As stated above, there is no guarantee that two GIS systems can produce equivalent external views from 'identical' data. When data is shared, key pieces may be lost. When data is updated, it may transform into contradictory or invalid data in another system. A robust conceptual model must be designed and adopted to represent either the smallest kernel of geographic information, from which all other information can be built or, at the other extreme, the largest comprehensive set of structures and relationships. While only the small kernel of building blocks is necessary, additional objects which are commonly used can make the implementation of the model more efficient. Figure 1 depicts the use of the model. If only a small kernel is adopted for the external view, each GIS may have to perform a great deal of computation to regenerate its internal view. Such a model is embodied in any spatial data transfer specification, but it may not be complete since each data transfer specification is designed with specific objectives in mind. BC-SAIF (Friesen and Sondheim, 1989) is one such data transfer specification under development by the Province of British Columbia whose objective is to define the common external view for general purpose GIS.

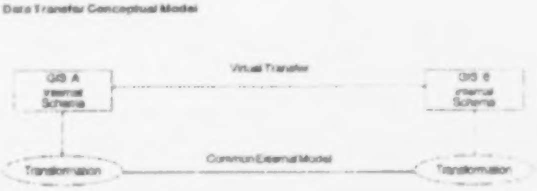

Figure 1. Geographic Information Systems can exchange data freely if there is an underlying conceptual model which facilitates data transformations. The actual data path, which includes transformations into and out of GIS systems, would be transparent to the user.

Perhaps the most crucial aspect of the data model used by GIS is the definition of links between the geometric entities and an attribute database. Conversion between graphic formats often sacrifices these links, making data exchange impossible. A common conceptual model would have to include a consistent method of associating attribute information with geometric entities. The associated attributes would include display characteristics and it is this level at which the complexities of the common model may become too great. Limitations on specific recognizable parameters must be defined to separate those pieces of information which can be transferred and those which must be regenerated within each GIS.

Common Network Protocol Model

The logical problem presented by the multiplicity of GIS internal schemas is paralleled by a similar problem in the GIS program design. The use of communication network protocols is intertwined in GIS and database software in many ways, making the interface between these programs and the hardware and other programs inconsistent. For example, it cannot be known a priori whether a GIS can interface to a terminal emulation program. In a very physical sense, the GIS may send information to the communications program which is interpreted by the program rather than simply transmitted. Many DBMS have attempted to overcome the problem of interfacing to communications network programs by including communications capabilities in the DBMS itself, creating a vertical integration of functions. Of course, in most cases this implies support of only one DBMS or one GIS. Connectivity is guarantied at the price of flexibility.

There is a simple solution to the logical problem of matching protocols: each GIS and DBMS should adopt the same underlying network communications model. A common model would define the interface between the GIS or DBMS and the communications software as well as the protocols for communication between different pieces of hardware and software. Such a model exists and has been acknowledged by the International Standards Organization as the Open Systems Interconnection (OSI) model. The model is based on seven layers of abstraction, each layer performing a different function in the network (Tannenbaum, 1981). Each node in the network must have software to support the functions of each layer. Each layer at a node communicates to a parallel layer at another node by means of defined protocols. The protocols represent virtual communication paths. Each layer is interfaced to the layer below it in a physical path. The result is that software on two different nodes can exchange information without explicitly knowing about the physical data transfer mechanism; only the protocol between the appropriate layers is necessary. Figure 2 depicts the use of the OSI model.

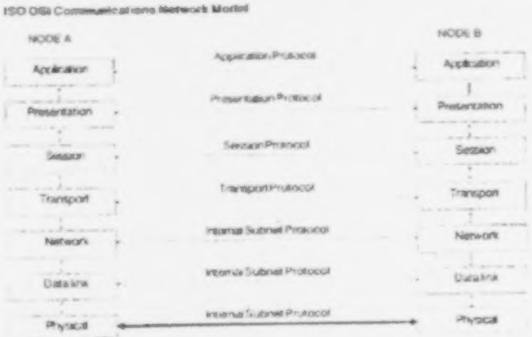
ISO OSI Communications Network Model
NODE A
NODE B
Application
Application Protocol
Application
Presentation
Presentation Protocol
Presentation
Session
Session Protocol
Session
Transport
Transport Protocol
Transport
Network
Internal Subnet Protocol
Network
Data link
Internal Subnet Protocol
Data link
Physical
Internal Subnet Protocol
Physical

Figure 2. The OSI network model permits the layers to communicate with each other via protocols over virtual links. The actual data transmission path is transparent to the user.

The power of the OSI model is that software responsibilities can be specialized and systems from a variety of suppliers can operate together. The proprietary nature of the software need not be lost or divulged, but the user and system designer have control over the elements of the network. However, such a model can only work if a) the interfaces between the layers are well-defined, b) the protocols at each layer are well-defined, and c) the vendors of GIS and DBMS confine their software to specific layers in the hierarchy. While these are important conditions, we have reduced the problem from a logical one to a technological one.

Examples

The diagrams on the following pages depict three network configurations for GIS. The simplest case is the star network Figure 3. This design provides access to the GIS and associated information via a central CPU and GIS. While there is access to the data, it is managed centrally. In many situations this may be an advantage. The use of a single GIS in a single location eliminates the need for a geographic data model which is different from the underlying conceptual model of the GIS. It also eliminates the requirement for the common network model, since there is only one CPU with which to communicate. This design has no flexibility to accommodate the needs of individual users and no use is made of distributed processing.

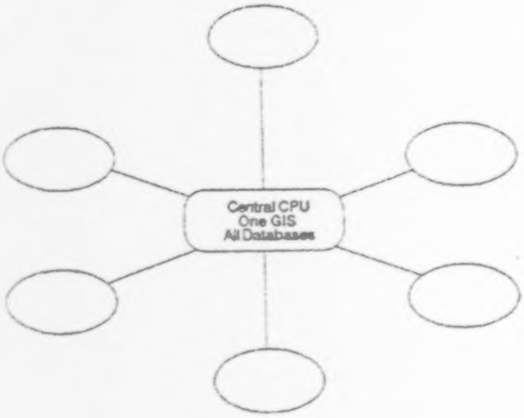
Central CPU
One GIS
All Databases

Figure 3. Star network with limited connectivity.

The second network configuration is called the Proprietary Connectivity Network, Figure 4. There is still a central CPU which would act as a file server, but there are now multiple GIS executing independently at each node. The data could be distributed, which would require node to node access and access to a 'corporate schema', but the use of a single type of GIS eliminates the need for a common external data model. In addition, the network communications software could be incorporated into the GIS or DBMS. Once again, the OSI model is not required. There is still no ability to alter the GIS at each node to match the needs of the user.

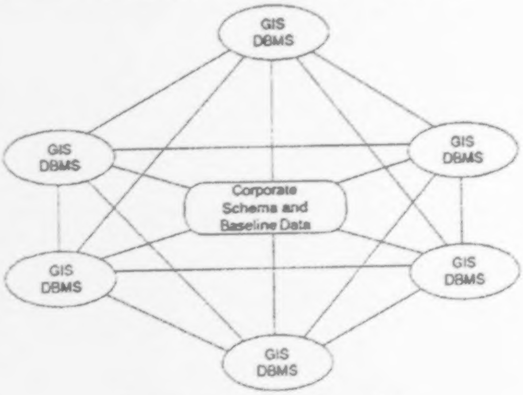
GIS DBMS
GIS DBMS
GIS DBMS
Corporate Schema and Baseline Data
GIS DBMS
GIS DBMS
GIS DBMS

Figure 4. Proprietary Connectivity.

The third configuration is called Complete Interconnectivity, Figure 5. The ideal situation allows independent nodes executing different GIS and DBMS. Data can be stored locally and baseline data can be managed at any one node.

This requires a common external data model for the exchange of data as well as adoption of the OSI model for interfacing the GIS to an underlying communications architecture. Flexibility is maximized as is standardization of the various component interfaces of the system.

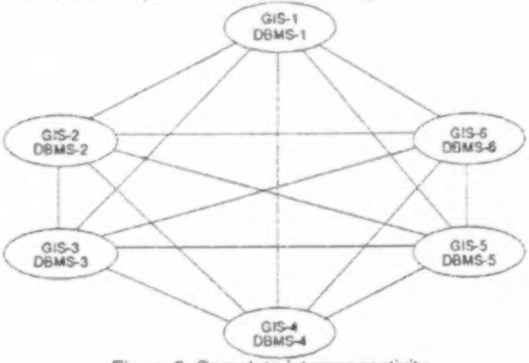

Figure 5. Complete interconnectivity

The actual situation would probably be a combination of all three configurations. However, while the insertion of star networks and local proprietary work groups is possible within the framework of the complete interconnectivity model, dealing with such complex configurations is not possible with the other configurations.

Logical Problems, Logical Solutions

The provision of GIS for wide access involves two logical problems: how can data be transformed from one GIS to another, and how can GIS and DBMS be integrated with communications networks? The solutions to these problems exist. A data transfer model has been created in a number of forms. BC-SAIF (BC Spatial Archive and Interchange Format) incorporates a data model which can serve as the external view for GIS. Based on existing specifications in Ontario (MDIF, 1989; MACDIF, 1988) and the US (SDTS, 1985; DLGE, 1989), it is an object-oriented approach to geographic information and includes the linkage between geometric data and business attributes. The basic building blocks of the data model are objects which are built from relations. Geographic objects include both geometric components (points, lines, polygons, pixels, etc.) and feature components (e.g. road, canal, estuary). Database schemas which carry the structure of the attribute information are included in the data model as well as 'meta' data which defines parameters for the transfer, or a subset of the transfer (projections, datum, units, origin, etc.). The data model encompasses raster and vector data and topological relationships between geometric entities. The formal specification for BC-SAIF will be published by the Ministry of Crown Lands by May, 1990.

The solution to the communications integration problem has been solved by the OSI model. More definition of the interfaces is necessary, but in principle the coordination of communications protocols and database software is documented.

Technological Requirements

A working system is not created by solving only the logical problems. The technological problems must be solved. In order to realize the complete interconnectivity configuration, a number of developments must be undertaken:

- GIS vendors must adopt the relational model for linkage to business databases and utilize SQL for manipulation of the associated databases,
- A common conceptual model, such as BC-SAIF, must be adopted for the common external view for the geographic data. Transformation software must be developed to permit import and export of data using this model.
- Translation speeds must be reduced to emulate on-line communications transfer rates. The transformation time must be within operational limits, and
- GIS, DBMS, Operating System, and Communications Software vendors must design software using the OSI model to permit interchange between system parts.

These are not simple requests and they may never be realized. However, the very fact that they can be enumerated provides hope that the truly interconnected geographic information system of the future can be realized.

Epilogue

Cynics can remind us that fifty years after the phrase was coined, there still isn't a chicken in every pot. And, logically, we do know how to produce enough food for a nation, it just hasn't been done. The land information world could end up in the same situation. Logically, we know how complete connectivity could be accomplished. Technologically, we know what developments are required in hardware and software. The question we must ask ourselves is, what are we willing to pay for flexibility and unified decision-making? Do we aim for using the appropriate tools in a varied and changing environment, or do we settle for using the currently available tool for all situations? Do we provide, no, demand, that everyone utilizing land information use a GIS, or do we expect our complex environmental decisions to be made with inappropriate tools? The decision is not a technological one, it is a logical one.

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The Corporate GIS Database in a Forestry Environment

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Abstract
A corporate GIS database containing land information maintained by a forestry company or government ministry, contains data that is shared by many different users to accomplish different activities. Users might be accessing data: to provide reports for management; to supply test data for planners; to help road engineers determine optimal routes and estimate costs; to function as the source for map creation; to supply quick responses to questions posed by the public. Where large numbers of people can access and potentially update the system, numerous problems may arise. This paper discusses the potential applications of a corporate GIS database in a forestry environment and addresses avoidable problems.

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GIS in a Networking Environment

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Abstract
Geographic Information Systems have traditionally been implemented using central host computers accessed through graphics terminals. In the mid 1980's, small departmental geographic information systems began to be implemented on PCs. Both of these technologies are now mature and in widespread use. In the late 1980's, geographic information systems have begun to appear on networked systems with the database geographically distributed over wide areas and accessed by similarly distributed users. The technologies required to implement distributed systems are dramatically different from those used for central host based multi-user systems or stand alone PC based systems. This paper identifies some of the special problems encountered in implementing GISs, the technologies available to implement a distributed geographic information system and the opportunities presented by such an implementation.

Introduction

Geographic information systems, as we know them today, were first implemented widely in the early 1980's on host computers accessed through ASCII graphics terminals. The host computer was typically a minicomputer or mainframe. The graphics terminals were typically Tektronix or compatible terminals. Terminals ranged from low cost PC compatibles with Tektronix Terminal Emulation to high resolution high cost terminals with extensive local storage for graphics segments, which allowed 'Local Zoom and Pan' and reduced the load on the central host computer.

The advantages of a host based computer are that the centralization of the database results in better control over database integrity as only one copy exists, and the centralized systems administration relieves terminal users of the need to know about systems administration. The principle disadvantage of a centralized host system lies in the sharing of the single host central processing unit by all of the graphics terminal users. As more and more users are added, performance degrades and becomes unpredictable. In addition, ASCII terminals have traditionally been connected to host computers by serial lines, which have limited speed for transferring graphics to terminals. This limits the speed of the graphics display regardless of the size of the host CPU.

In the mid 1980's, GIS software became available on microcomputers allowing the implementation of small geographic information systems based on single user PC compatibles. The principle advantage of a PC based system is its low initial cost. A second advantage is predictable response time, since the user of a PC based GIS is the only user on the system. The principle disadvantage of PC based systems is the inability to share data among several users without resorting to complex PC networks and the requirement for the user to be his own system and database administrator. In the late 1980's, workstations connected in local area networks became a viable alternative to the traditional host based minicomputer systems and the stand alone PC based systems. These systems offer many of the advantages of the host based system and PC systems without the disadvantages. For instance, databases can be centralized on a workstation server, which all the workstations can access, but computing is distributed to the individual workstations, resulting in predictable response time. In addition, workstations operate over high speed local area networks, resulting in extremely fast graphics display. This technology has now become almost completely standard when implementing a GIS.

The next wave of geographic information system implementation will be workstation based networks distributed over large geographic areas accessing multiple databases stored on different file servers. Each of these databases may be maintained by different organizations, using software and hardware from different manufacturers and using a combination of local and wide area networking technology.

Successful system implementation presents a major technical and administrative challenge.

Why Distributing GIS is a Special Problem?

Geographic information systems are very different from most traditional data processing applications and, therefore, require different approaches to implementation.
These approaches include:

- GIS requires data to operate. A geographic information system is more than hardware and software. Large quantities of data are required to merely function. Many traditional data processing applications such as accounting generate their database through use. This is not the case with GIS.
- Data volumes in geographic information systems are enormous. Much of this data is static with only a small percentage changing in any given period of time, in contrast to many traditional data processing applications where the data is changing rapidly. For example, banking systems have relatively small databases compared to the number of users but the database changes rapidly with a large percentage of the database being completely changed every month.
- Transactions in a geographic information system are very long, extending perhaps for hours, days, or even months. Transactions may involve many different databases with human intervention at several stages of the transaction, in contrast to most traditional data processing applications, such as banking, where transactions rarely exceed a few seconds in length.
- Queries in a geographic information system are very resource intensive, requiring the scanning of large data files and enormous amounts of computing power to process a single query. Since the query may result in the graphical presentation of data, the query could last for several seconds or minutes, in contrast to traditional character based systems, where a query may last a few seconds and present no more than a few hundred characters of data. The graphic presentation of large quantities of geographic data may involve the delivery of several megabytes of data.
- Analysis of information contained in a geographic database requires the application of computational geometry and is very compute intensive. Computers performing this analysis must be capable of not only high speed input and output to scan large quantities of data but must also have powerful computational abilities to perform functions such as polygon overlay.
- Data required for geographic information systems is frequently obtained from many different sources and integrated by the end user. The user frequently does not have control over this data since the data is maintained at the source and not by the user.

These special problems result in the need for hardware architecture that has the input and output capacity of a traditional mainframe computer and the computing power for each user associated with a high performance personal computer or technical workstation. A workstation network with a high performance file server satisfies this requirement for a group of users located within one building or campus where the networks connecting servers and workstations are very fast. However, as soon as the workstations are separated by more than a few hundred meters, speed of the network drops dramatically, resulting in very slow response times for graphics display and file I/O, making the implementation of a workstation network with centralized data storage impractical.

A Technology Tutorial

Understanding how geographic information systems can be distributed over wide geographic areas requires a basic understanding of the technology available for this task. Even managers contemplating the implementation of distributed geographic databases should acquire a solid understanding of the technology at a conceptual level before proceeding. Technology used to implement distributed GIS's includes:

- Terminals (X & ASCII),
- Workstations (DOS & UNIX, dataless and dataful),
- Servers (Compute and File),
- Local Area Networks (LANS - Ethernet and FDDI),
- Wide Area Networks (WANS - X.25, SNA, Dialup and dedicated phone lines),
- Extended LANS using fibre optics,
- LAN bridges,
- Internetwork routers, and
- Telephone services.

All of these technologies are needed to some degree to implement distributed geographic information systems. A particular distributed GIS may involve several or all of these technologies.

Terminals

Terminals used for GIS fall into two categories. ASCII terminals, such as a Tektronix terminal, encode graphical data into ANSI standard characters and transmit these as a so-called 'escape sequence'. They operate very effectively over low speed lines and, in fact, provide acceptable graphics display speed for medium sized data sets if the line speed is operating at 9600 bps or faster. A principle disadvantage of ASCII terminals is their inability to conduct more than one session with the host computer at one time. In other words, only one window can be opened at a time.

X-Windows terminals communicate with the host computer using the X protocol, developed at MIT in the mid 1980's. The X protocol is a bit mapped protocol which means that an application has control over every pixel in the graphics display, providing considerably more flexibility than ASCII terminals. In addition, X- Windows, as the name implies, allows the use of multiple windows to conduct simultaneous sessions on several host computers or several sessions on a single host computer. However, since X-terminals manipulate information at the bit level, they require much higher speed communication with a host computer to provide an acceptable response time. X-terminals displaying geographic information generally must be connected to the host computer over a high speed local area network.

Workstations

Workstations are generally implemented in one of two configurations, dataless workstations, which contain no data and must access a file server over a network or dataful workstations, where the workstation has a significant amount of local disk storage and stores all or part of the database that it is using on its own disk storage. Workstations are generally based on the UNIX operating system but may be running a proprietary operating system such as VMS or MS-DOS. Dataless workstations must be connected to a file server over a high speed local area network while datafull workstations may be connected to a remote file server over lower speed telephone lines where access to the remote file server is infrequent.

Servers

Servers in a distributed system perform two functions. File servers store large files or databases and are generally configured with large quantities of very high speed disk storage and special hardware designed to speed up the retrieval of data from these files. The Network File System (NFS) is software associated with the UNIX operating system that allows dataless workstations on a network to access a file system on a server and treat it as if it was a local file system. In the relational database world, products such as Oracle SQL*NET allow dataless workstations to issue SQL commands over the network to the file server, which retrieves the appropriate data and sends it to the dataless workstation.

Compute servers are specialized systems on a network which have very powerful CPUs that provide computing services to other network devices. The most common use of a compute server is in an X-Windows network, where all computing except that required for graphical display on the X terminal must be done by a server. A traditional host based minicomputer with ASCII terminals connected to it is both a file server and compute server.

Local Area Networks

Local area networks are very high speed networks (10 million bits per second (bps) and up) which connect workstations and X-terminals to compute servers and file servers. The most popular local area network is based on ethernet, a protocol developed by Xerox and widely adopted by the computing industry. Two alternative local area network technologies are IBM's token ring and a new fibre optic based ANSI standard called Fibre Distributed Data Interface (FDDI). The token ring operates at 16 million bps while FDDI operates at 100 million bps. Ethernet can operate over coaxial cable, twisted pair wiring or fibre optic lines.

Local area networks are limited to several hundred meters in length, although they may be extended up to 1 000 meters by using repeaters. Local area networks generally require dedicated cabling, which can be very expensive.

Ethernet, once thought to be a very high speed network, is now too slow when more than 5 or 6 dataless workstations are connected to a file server. FDDI, expected to be widely implemented in the early 1990's, enjoys an additional advantage of being able to extend up to 200 kilometres in length.

Wide Area Networks

Wide area networks are generally implemented either the international X.25 protocol or IBM's proprietary SNA network protocol. Wide area networks may also be implemented using dedicated telephone lines or dialup modems to connect terminals to a remote host computer. Wide area networks are limited by the speed of available telephone lines and rarely operate at speeds over 9600 bps.

Extended Local Area Networks

In the last year, products have become available to extend local area networks, using fibre optic cables, to several kilometres. These products are generally referred to as LAN repeaters and can extend an ethernet network up to 20 kilometres. Extended LANS are very expensive because they require dedicated fibre optic lines and expensive repeaters.

LAN Bridges

Local area networks separated by more than a few kilometres may be connected together via LAN bridges. These devices cost in the range of $7 000 - $10 000, which link one ethernet network to another using a medium speed telephone signal, typically running between 56,000 bps up to 1.54 million bps. Users of workstations connected to one network see the other network as an extension of their own. No special software is required to communicate between the two networks. Some limited file service capabilities can be implemented over such a network, although graphics performance over the bridge is poor.

Internetwork Routers

Internetwork routers are a variation of network bridges, but communication between geographically distributed local area networks does not necessarily take place over only one bridge or route, but is routed over the highest speed line available at the time, hence, the term internetwork router.

Telephone Communication Services

Telephone line services for connecting local area networks, and ASCII or X- terminals to file and compute servers falls into several categories. The lowest level of service is the dialup telephone line, where modems at each end provide a direct connection between a terminal and host computer. The second level of service is a dedicated 9600 bps line with modems at each end, providing simple services such as file transfer and communication between two remotely located workstations. Higher speed telephone services such as the 56 000 bps lines allow local area networks to be bridged for file transfer and limited file service capabilities. The highest level of telephone service is the 1.54 megabit service which is extremely expensive and is only practical where huge volumes of data are passing between sites on a regular basis.

Client Server Architectures

The implementation of distributed geographic databases is now being based on a new computing architecture called a client server architecture. As the name implies, clients, such as workstations receive services from servers, such as access to large databases or file systems or powerful compute services. Effectively, this means that two major tasks in performing a geographic database query are divided between two systems; the file server retrieves the data from the file storage system and the workstation performs the computations necessary to complete the analysis and display the data graphically.

The Implementation of a Distributed Geographic Information System

Most successful distributed geographic information systems in operation today are based on a mix of the technologies that have been discussed. A fundamental principle that must be adhered to in implementing a distributed database is ensuring that data is constantly kept up to date. This means implementing update systems at the source of the data and publishing this data to others who are storing it on remote workstations or servers but are not in a position to update the data themselves.

This requires a complex series of transactions that ensure updates are triggered on all systems maintaining copies of the data. This may involve an automatic update of a remote database or merely notifying the administration of a remote database that new data is available, putting the onus on him to retrieve the new data and update his own database.

The implementation of such a system demands cooperation of many agencies involved in maintaining data and an understanding by each of these agencies of the impact of changes to the databases of others using copies of their database. In addition, each of the custodians of these databases needs to understand the structure of other systems using their database and must transmit the changes to their database in a format useful to the user.

Examples of Distributed Geographic Information Systems

The Newfoundland Department of Forest and Lands in Corner Brook, Newfoundland, has taken the traditional approach to distributing geographic information systems services to users in 13 remote district offices. The Department installed a large minicomputer in Corner Brook with dedicated telephone lines to each remote office, which accesses the central database by Tektronix terminals and has a plotter connected via the dedicated line to the host computer. This approach is technologically proven and works very well.

The New Brunswick Department of Natural Resources has recently installed a network of SUN workstations connected by ethernet to their existing host minicomputer. Their entire database for New Brunswick is stored on the Prime minicomputer and a subset is stored on a SUN workstation server. Updates are carried out on the SUN network and posted back to the Prime minicomputer database, maintaining concurrency between copies of the database on the SUN network and on the Prime host. Users at the Department connect to the ethernet network through a twisted pair telephone system installed by the New Brunswick Telephone Company. Specialized equipment provided by NBTel allows the twisted pair network to run at full ethernet speeds and extends over the Department's entire building complex. The Department's regional and district offices will connect to either the Prime or SUN network, using ASCII or X- terminals connected over dedicated phone lines.

One of the most complex distributed geographic information systems in Canada is the Ontario Land Records Database. The land parcel database is maintained on an IBM mainframe and an Intergraph VAX in Toronto. Municipal users maintain a copy of portions of this database on their systems. Changes are posted over the SNA network from the IBM mainframe to the municipal systems on a weekly basis. This system is currently implemented in Oxford County on a pilot basis and is expected to be extended to other municipal users in the near future. In Oxford County, the geographic portion of the parcel database is being updated by the County. Soon, changes to this database will be posted back to the Intergraph system in Toronto via diskette. The database in Oxford County is maintained on a Prime minicomputer and a SUN workstation network. Users are connected to the network over dedicated telephone lines and use PCs emulating Tektronix ASCII terminals to access the various databases. Resource intensive users have SUN workstations connected to the local network, and can log on to the IBM Mainframe in Toronto and the SNA network.

The Alberta Government, through the Alberta Research Council and the Alberta Planning Board, is implementing a distributed network of SUN workstations in the Edmonton area connected by internetwork routers running over 9600 bps dedicated telephone lines. This pilot project is investigating the feasibility of municipalities maintaining data which changes at the municipal level and distributing it to the provincial government users, and the provincial government maintaining data which changes at the provincial government, such as the Alberta Land Titles System, and distributing it back to municipal users over the network.

In British Columbia, MacMillan Bloedel has a network of Prime minicomputers, SUN workstations and IBM PCs maintaining their forest inventory database. A large Prime minicomputer contains the master database and a smaller Prime minicomputer contains a subset of the database to support a number of analysis users. A network of SUN workstations is connected to the large Prime by ethernet. These workstations are used for inventory update and resource intensive analysis and reporting applications. District offices are using a PC based GIS, which is updated on a regular basis from the corporate database, using disk transfer or by transporting a subset of the database to the district on a laptop computer.

These are a few examples of organizations which have implemented distributed geographic information systems across Canada.

Conclusion

The implementation of distributed GIS, although technically complex, is largely an administrative problem. Organizations must agree on common data exchange formats and network protocols, as well as frequency of updates of remote databases, who has access to information and a host of other issues. Government organizations have traditionally operated in relative isolation and have been structured in a hierarchical fashion. The implementation of distributed geographic databases will require a complete rethinking of this philosophy since geographic information systems cut across organizations. The next decade will see rapid changes as organizations adapt to the requirement for greater communication needed for the implementation of geographic information systems.

Making GIS Work

Session C7
A Management Perspective on Data Sources

Spatial Forest Information For Natural Resource Managers

GIS Data Exchange: Standards and Formats

Creation of a Forest Inventory Database Using Airborne Digital Imagery and GIS

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Spatial Forest Information for Natural Resource Managers

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Abstract
For the natural resource manager, most forms of spatial forest information are derived from aerial photography. This paper discusses what kinds of aerial photos and other forms (topographic and computer maps, satellite and video imagery) of spatial information are available for management of forests. In addition, current technology to interpret and translate information from aerial photos into geographic information systems will also be discussed. Advantages and disadvantages are addressed in addition to showing forms of output (maps and images) from geographic information systems.

Introduction

"Where are the trees?" That is the question. To answer this, one must have some means of locating them. The scope of this article is to present an overview of available *spatial* data or information (one person's data may be another's information) for foresters who are beginning to look at geographic information systems (GIS) to find their trees.

Before going any further, a statement of responsibility for GIS users needs to be examined and understood:

> "There is an understandable human tendency to hope that somehow new technology will solve today's problems in data acquisition and mapping and that tomorrow life will be easier. Certainly the proponents of each technological advance would like to have us believe this. If we fail to identify today's problems correctly, however, we may find ourselves in an even more difficult position tomorrow as sensors and systems proliferate, each with its own set of limitations.
>
> No data acquisition system is cheap, be it aerial photography or space imagery, and to be able to make cost-effective judgments, considerable knowledge will be required, not only of sensor capabilities and job requirements but also the changes that must be made to accommodate differing data types in on-going mapping systems. The user has expectations but he also has increasing responsibilities." (Fleming, 1984)

These are important words of advice which one should contemplate when deciding how to capture spatial information for geographic information systems.

Information

In general, foresters are planners and managers of not only forests, but also of wildlife, recreation, range, roads, etc.. As a traditional example, foresters must make decisions of how much forest to cut, where to cut, when to cut, where to invest in regenerating the forest, and what methods to use. To make these decisions, foresters collect and analyze tremendous amounts of information. To obtain information, foresters consult hundreds of maps, aerial photos, reports, forms, and even scraps of paper stored in any number of filing cabinets. With the advent of computers, databases and geographic information systems (GIS) are becoming an 'electronic' filing cabinet and a map analysis tool in today's forestry offices (Martin, 1985). These computer based information systems can perform in seconds a multitude of calculations which used to take days.

Even though geographic information systems are becoming mandatory for any natural resource management organization, designing, modifying, or adding an effective information system for an organization is clearly a complex and demanding task (Baskerville and Moore, 1988). It requires taking into account a number of factors: the organization's technical level, its environment, the nature of its employees, its size and structure. Because these factors influence the constructive use of information, a single information system rarely works for all situations.

A particular form of information, spatial information, usually describes the location of a particular feature and attributes or characteristics about it at a particular point in time. A GIS is nothing more than a tool to more easily manipulate, analyze and transform spatial information (Mulder, 1986). However, before one can use a GIS, the resource manager must first obtain spatial data and information for GIS input.

Inputs

Maps could be thought as a fundamental source of spatial information for any forestry organization. They come in many forms depending upon their primary purpose and which organization produces them. Topographic maps and orthophoto maps are probably the most common and the most used. A current trend with many resource organizations is to convert paper maps into computer maps by digitizing and scanning (Allam and Wong, 1986; Leberl et. al., 1986). Each digitized or scanned entity is given one or more attributes describing the nature of the feature. The USDA Forest Service, for example, is in the middle of a five-year cycle to digitize all layers of their primary base series (7.5 minute topographic maps) into a preliminary computer map database. These files will be cleaned, merged, updated, edited, and assigned more attributes later on when the Forest Service settles on which geographic information system to purchase for its organization.

Aerial photos also contain spatial data which comes in many types and sizes. Black and white, black and white infrared, color, and color infrared photos are the four standard types used for mapping resources. Each one has particular advantages and disadvantages over the others depending upon its use. The size of aerial photos can also vary due to the type of camera and the amount of enlargement from the original negative or positive transparency to a paper print.

Small format photos from 35mm or 70mm cameras are cheap and easy to acquire. In addition, the cameras tend to have higher lens resolutions over 9" x 9" mapping lenses. Small format photography works rather well for low altitude, small area projects (Meyer and Grumstrup, 1978).

Of course, most foresters are familiar with the type of photography from standard 9" x 9" mapping cameras. However, there are other types of photography available to foresters from NASA (Doyle, 1984). Large Format Camera (LFC) photography (9" x 18"), panoramic photography (5" x 50"), and standard 9" x 9" mapping camera photography are acquired throughout the North American continent using the ER-2 aircraft, which is similar to the U-2, at high altitudes. Figure 1 illustrates acquisition and coverage characteristics for the ER-2.

With the emergence of new remote sensing tools such as thermal, radar and multispectral scanners on aircraft or satellite platforms such as the Landsat Thematic Mapper, the Daedalus Multispectral Scanner or the Airborne Visible/Infrared Imaging Spectrometer (AVRIS) on the ER-2, the question is now "what kind of additional information can be extracted for management of natural resources?" (Aldrich,

Sensor Coverage

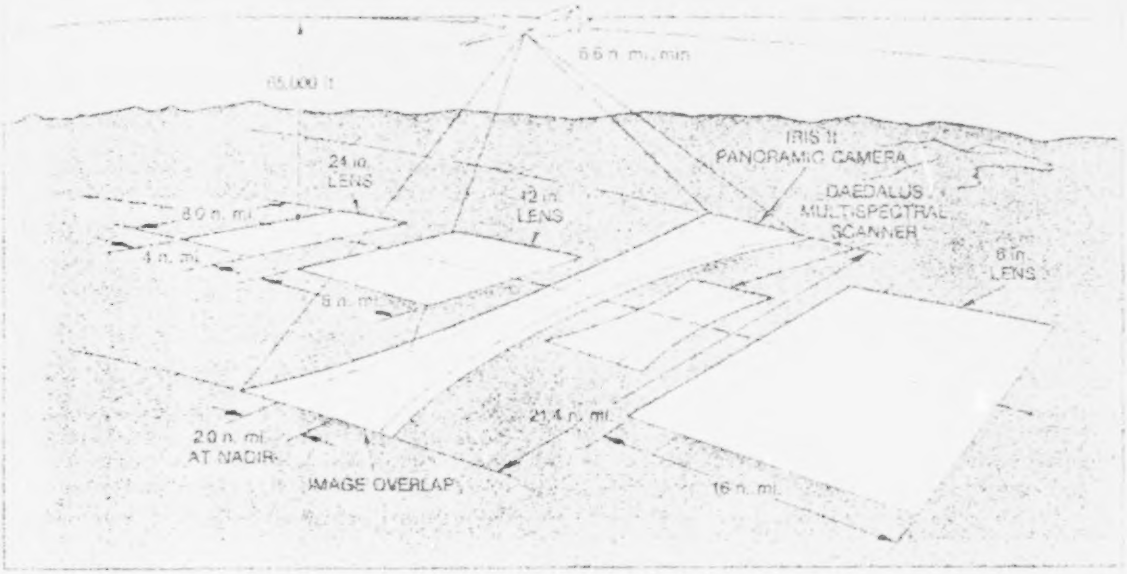


Figure 1. Sensor coverage for NASA's ER-2 aircraft.

1977). There is no doubt these remote sensing tools offer different information than aerial photography (Ahern and Leckie, 1987). Thermal scanners provide active forest fire images. Landsat has proven to be a worldwide extensive forest mapping tool. However, it still remains to be seen if these new remote sensing tools can be as cost-effective or efficient as aerial photographs for the day-to-day management of forests for all disciplines (timber, recreation, range, soils, etc.).

Black and white, color, or even color infrared video cameras are overlooked as simple to use remote sensing tools (Meisner and Lindstrom, 1984). If a forest manager can put up with low resolutions (300 to 400 lines of resolution per screen) inherent with today's video recorders, an aerial video image can be easily acquired, frozen, using a frame grabber, and transferred into most raster-based image processing or geographic information systems for further analysis.

Traditional surveying methods will continue to be important inputs into GIS through the use of automated data capture procedures from surveying instruments. The NAVSTAR Global Positioning System (GPS) will introduce a new means for gathering highly accurate surveying data through the use of portable receivers to obtain position fixes from orbiting satellites. Presently, a GPS receiver will only work during certain portions of the day due to current satellite coverage. This limitation will be overcome when the full constellation of 18 satellites is deployed in 1992. To briefly illustrate the potential of GPS, a receiver can be mounted on a vehicle and driven down a newly constructed road to accurately map its true X-, Y-, and Z- coordinates. The data can be dumped into a GIS to update the roads information layer (Lange and Kruczynski, 1989).

Sources

In Canada, the primary source for spatial information such as maps or aerial photos is:

Energy, Mines & Resources Canada
Earth Sciences
Surveys and Mapping Branch
615 Booth Street
Ottawa, Canada K1A 0E9

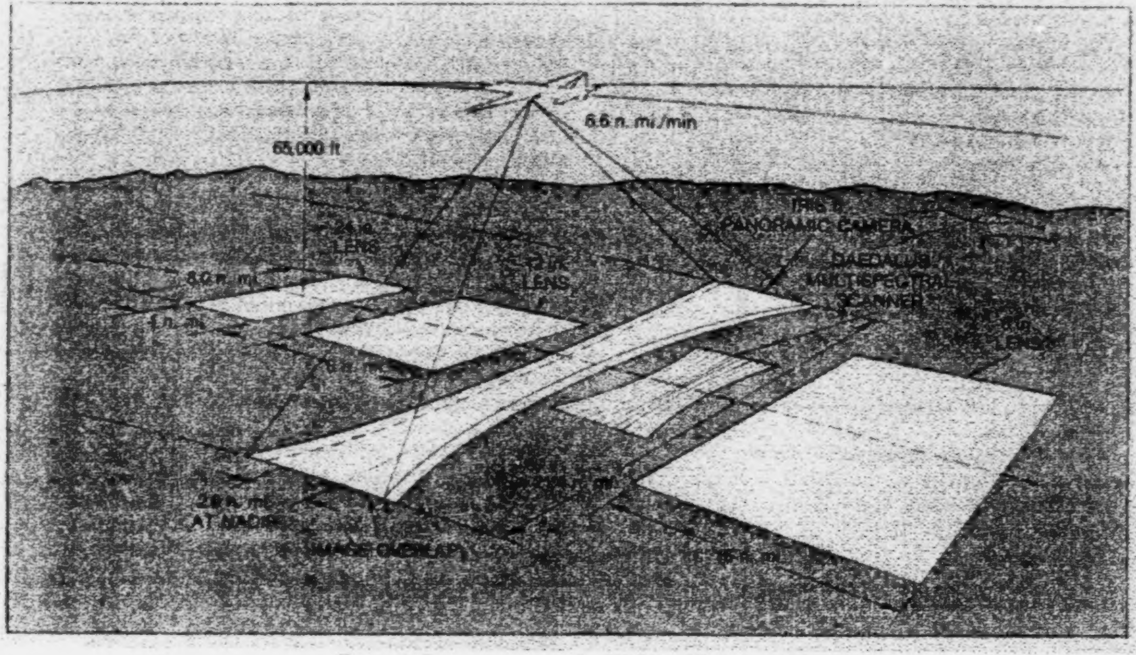
In the USA, the primary source for all forms of spatial information is:

1-800-USA-MAPS

This is the Earth Science Information Center hotline which acts as an information referral service for all federal agencies. It is run by the U.S. Geological Survey.

Other sources for maps, aerial photos, or digital data may be found with provincial, state or local governments. Natural resource agencies, highway departments, or tax revenue commissions within these local governments may have the kind of spatial information you may be looking for. Private photogrammetry companies may also maintain a source for spatial information.

Sensor Coverage



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More information about NASA's image acquisition programs can be obtained by contacting:

High Altitude Aircraft Program
NASA/Ames Research Center
Applications Aircraft Data Management Facility
Mail Stop 240-6
Moffett Field, CA 94035
(415) 694-6252

In Canada, the Forestry Canada contact for NASA is:

Walt Moore
Northern Forestry Centre
Forestry Canada
5320 - 122 St.
Edmonton, AB T6H 3S5
(403) 435-7210

In the USA, the USDA Forest Service contact for NASA is:

Paul Ishikawa
Nationwide Forestry Applications Program
USDA Forest Service
2222 West 2300 South
Salt Lake City, UT 84119
(801) 524-4580

For satellite data, check with your EOSAT (USA), SPOT (French), or Contitrade (USSR) representative.

Interpretation and Translation

Once you have your spatial data, the next step is getting it into your system. With the digital forms of spatial data, such as computer maps, satellite imagery, computer data from surveys, etc., this is relatively easy since they are already in a form in which computers can handle. There are numerous investigations on how to handle remote sensing and geographic information system integration (Archibald, 1987; Aronoff and Parliament, 1987; Ehlers et. al., 1989; Goodenough, 1987; Zhou, 1989). However, these studies are concerned mostly with integrating data from satellite images.

With aerial photographs, there are ways to capture data digitally from interpreted photography. One of the easiest ways is to simply digitize features directly off the aerial photo. A word of caution, aerial photos are *not* maps. Features are radially displaced on aerial photographs, especially in mountainous areas. Radial displacement can be reduced to negligible proportions by using photos taken with cameras equipped with long focal length lenses such as the LFC.

Another way is to have your photographs scanned and transferred into a GIS to be viewed as an image on the monitor. Current scanners can achieve 500 dots per inch resolution. The photo image can also be rectified into an orthophoto image, removing tilt and radial displacement errors, using digital elevation model data. The GIS user can then delineate objects of interest with a mouse or cursor on the screen. Some of the more recent graphic systems support viewing aerial photography in stereo. However, the user will have to determine whether these systems are cost-effective.

The best way to capture information accurately from aerial photography while removing the radial displacement is through the use of analytical plotters. Most analytical plotters today will capture information digitally which can be transferred to a GIS. Even PC-based micro-analytical plotters have the same capability of digital information capture but with less accuracy (Reutebuch, 1987; Warner, 1988).

There is a missing link between geographic information systems and analytical plotters which has not been addressed by the manufacturers. Although analytical plotters can capture data digitally, there currently is not a system in which GIS files can be superimposed graphically on stereo photos within analytical plotters and updated or queried interactively. Many of the major analytical plotters such as Kern DSR-11 or the Intergraph InterMap Analytic do offer graphic superimposition but without direct links to any GIS.

One reminder on interpretation of imagery. When it comes to classifying information from imagery using computer image processing systems, these systems create information from images (photographs or satellite data) based mostly on spectral (color or tone) values. This is only one piece of a visual data puzzle. The other pieces are brightness, shape, texture, pattern, size, shadow, height, and context (Rabben, 1960). Human vision, actually, the brain, assimilates these puzzle pieces into information (quite remarkably, when one thinks about it). Sometimes, users of aerial or space imagery tend to neglect their ability to see and interpret images with their own eyes.

Outputs

Simply put, spatial output can come in four forms from a GIS:

1) a picture of your GIS video monitor
2) pen plotter map
3) inkjet or electrostatic plotter map
4) film recorder image

The easiest is number one. Get out your Polaroid and snap a shot of your monitor. Number two is probably the most common form of output for vector-based GIS. Raster-based GIS usually produce inkjet or electrostatic maps (Number 3). The fourth type can be common to all types of geographic information systems but can be an expensive technique.

Summary

There are many different kinds of spatial information available to foresters. Foresters need to look at and be aware of all tools which get the job done inexpensively, effectively, and efficiently. Foresters constrained by operations budgets need also to look at which combination of spatial tools gains them the most accurate, current information.

Aerial photography should not be ignored as a primary spatial data input to GIS. This is an important point one should consider before they decide to have all layers from a twenty-year-old topographic map digitized as the primary spatial input information for their GIS. It may be more efficient, accurate, and economical to compile information into a GIS directly from recent aerial photography. It will be even more effective to have a simple to use, micro-analytical plotter system which is linked directly into a GIS. This is so forest resource managers can update and maintain their own spatial information without relying on someone else's interpretation.

Foresters should not jump on every new remote sensing or geographic information system bandwagon that comes along without extensive and accurate demonstrations. How a new system works and its limitations must be demonstrated (DeGloria and Benson, 1985). New remote sensing systems such as satellite imagery tend to have unique capabilities which complement existing photographic systems and should not be sold as a replacement. Otherwise, non-photographic remote sensing will be viewed as an elitist system over photographic remote sensors (Meyer and Werth, 1989).

There are elements of the remote sensing community that believe the time has come to recognize the past and present limits of computer-based image interpretation (Ryerson, 1989). This does not imply a reversal back to manual image interpretation methods but to recommend the use of all manual and digital techniques available to achieve the best, most efficient, least costly, classified and interpreted information possible.

To conclude, I would like to quote from Michael Helfert (1989), which I believe states what the aim of any user of remote sensing data should be:

> In summary, I feel that we in the remote sensing community should use all data sources, regardless of data form or originating platform. Our goal in the larger scientific community should be larger than the data, that is, we should attempt to achieve understanding by all means possible of the processes operative on this particular planet or any other heavenly body that we may, at some future time, seek to explore. These goals are achieved by utilizing both proven and imaginative technologies to gather data that will aid in planetary understanding and modelling, and not by the debilitating arguments on the advantages and disadvantages of man versus machine, or digital versus analog data structures.

Disclaimer

The mention of products and companies by name does not constitute endorsement by the USDA, nor does it imply approval of a product to the exclusion of others that may also be suitable.

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GIS Data Exchange: Standards and Formats

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Abstract
As GIS and related systems grow in importance, there will be a critical need for data exchange and sharing between organizations and between components within an organization. This paper discusses the results of an investigation into the standards and formats used to exchange GIS information, including background concepts and issues, current digital data exchange formats and standards, vendor support of exchange formats, current status of GIS data exchange in Canada and internationally, trends in GIS data exchange, and the concept of an organization developing a GIS data exchange strategy.

Introduction

Exchanging geo-referenced data has become a complicated issue due to the diversity of information which may be exchanged. The source of the data may be topographical, cadastral, hydrological, geological, or even social statistical. The structure of the data may be vector, raster, or both, it may contain non-spatial attribute data and have topological relationships specified. Further complications are introduced because of the large volumes of data involved.

There are many benefits which may be realized through data exchange. For example, data may be captured once, and not recreated for every use, GIS functions may be performed on the system best suited for the work, modifications and further developments to data may be carried out more rapidly, and system migration is possible, upwards as well as sideways.

Data Exchange Alternatives

There are two basic alternatives to handling data exchange, standardizing on one particular system so no data conversion is necessary, or developing mechanisms for converting data between different systems. Except in restricted circumstances, standardizing on a specific system is not practical, especially given the inevitable requirement to exchange data with systems beyond the organization. There are also two approaches to the converting data alternative; the 'neutral format' exchange, where data on one system is converted to a format independent of either system, then converted to the format of the second system, or the direct conversion approach, where a translator converts data from one system's format directly to the other's.

To exchange data between all possible pairs of n systems, using a neutral format, 2n translators are required, one each to read and write. For specialized direct translators to handle data exchange between all possible pairs of n different systems, n(n-1) translators are required. As n exceeds 3, this rapidly becomes much more than the 2n translators required by the use of a neutral exchange format. Since there are already a large number of systems in existence, being used by a variety of users, the direct translation approach is not considered viable as a long term solution.

Another factor which may be important is that a common exchange format can also be a common archival format. Digital cartographic information is likely to be of historical significance in the future. The fact that this data can be so easily modified and deleted is of concern to archivists and historians.

GIS Data Exchange Standards

While the use of the word 'standards' with regard to GIS data exchange is often used, there are in fact no GIS data exchange standards. Rather, there are specifications which may over time, with consensus, become standards. The entire process of developing and refining GIS data exchange standards is a time consuming and complex procedure. Standards allow users to exploit new technology while protecting initial investments. From a vendor's point of view, exchange standards can also be cost effective, since a limited number of exchange mechanisms will need to be supported. There are many standards being developed to address different and often specialized needs. In other cases, new standards are evolving to meet needs which were not apparent when previous efforts were undertaken. Where one standard has reached a point of maturity, another one may still be in the maturing process.

Standards Requirements

Standards are developed from, and evaluated against, a set of requirements, which often overlap in scope, are contradictory, or are too broad or too general to have real meaning. Some example requirements are:

- archival capability,
- ability to handle associated attribute information,
- support for blind interchange (self-describing),
- implementation independent of any specific computer language,
- allow for varying coordinate precision,
- ability to handle both 2-D and 3-D coordinates,
- support for data compilation information
- include a data dictionary within the exchange mechanism,
- specify data quality information,
- transfer data subsets or change-only information,
- link to, or relate to, conventional databases,
- easy to use,
- easy to implement,
- efficient handling of data (computing time, storage space),
- handle errors in the data set (data validation procedure),
- expandable in a consistent manner (can add to the standard),
- a feature classification scheme,
- operate across a variety of hardware/operating environments, - use existing standards,
- be independent of the transport medium, including networks,
- multiple data sets on one volume, and multi-volume data sets,
- support a range of map projections and datums,
- handle raster data within the same format,
- seamless data handling (i.e., no map sheets).
- handle data with or without explicit topology,
- non-proprietary (vendor-independent).

Within a standard specification, some requirements are given higher priority than others. Furthermore, some of the requirements refer to areas in need of standardization themselves, independent of data exchange, including:

- terminology, the majority of data exchange standards or specifications do not include a glossary,
- spatial referencing; it is important that the coordinate system, projection, etc., be specified in some standard manner,
- object representation; an agreement on how various cartographic objects are to be represented,
- data quality specification; various ways at different levels,

- feature classification; while closely linked to the actual data exchange mechanism, it is also an issue on its own (feature classification may be linear, hierarchical, or network in form).

In summary, standards are interrelated and many standards are built upon other standards whether implicitly or explicitly. A standard should build upon existing standards, and be capable of including new ones when they are adopted.

Data Exchange Conformance

Conformance deals with ensuring that conversion software is implemented and tested such that it meets the specifications for the standard. Broadly, this involves making sure that any specific conversion software implemented behaves in a manner consistent with any other implementations already in existence and that adequate test data sets are available such that conformance can be tested. Implementation guidelines must be defined and available. It also means that data exchange standards are developed such that they can be tested. A proper conformance section should be included with any specifications of a standard.

Conformance does not test the standard itself but tests implementations of the standard with regard to its specifications. Conformance usually involves falsification testing, using sample cases that test as many of the requirements of the standard as are feasible. The suite of test data, or validation suite, tries to find errors in the implementation. If errors are found, then the implementation does not conform to the standard. Of course, the absence of errors does not necessarily mean the converse. Absence of errors may mean the test suite was not extensive enough to find all errors. Falsification testing can determine non-conformance to a standard but not assure total and complete conformance.

Problems with the creation of test suites for falsification testing are that it is difficult to test for all data value occurrences and it is difficult to decide to what extent testing should be carried out, the gain in completeness being weighed against the time and cost of too large a test suite.

Steps in Testing

A number of tests are usually performed in order to determine correctness. Primary tests include reflection, transmission, and closing-the-loop.

Reflection Test - A test in which system data is converted to a neutral format and then converted from the neutral format back into the system format. The initial data and the subsequent 'converted' data should be identical (symmetry).

Transmission Test - A test in which data in one system is converted to a neutral format and transmitted to a second and different system. A concern here is how to quantify or measure the similarity or difference of the data on the two different systems.

Closing-the-loop/Closed-Loop/Loopback Test - Data in one system is transmitted to another system, processed, and then transmitted back to the originating system. The original data and the subsequent processed data should be the same.

While the importance of developing test data sets has been identified, in the course of this study, it has been found that there are very few test data sets available for conformance testing. Those which are available tend not to be rigourously defined. Much of what would be included in a data set depends upon the structure of the exchange format and the use to which the exchanged data would be put.

Data Exchange - User Perspective

The situation of taking data from one system and converting it to another, either directly or via a neutral exchange format, is usually far from straightforward or simple. The process, as it is currently practised, often requires a number of intermediate steps.

At the user level, a number of very real practical problems must be addressed and overcome. These include:

- availability of translation routines,
- functionality of translation routines, which may be limited,
- poor match between data structures and data models,
- different operating systems and file structures,
- different hardware platforms/system architectures,
- storage medium/file sizes,
- data/coordinate precision varies between different systems,
- different feature classification schemes,
- only graphics exchange may be allowed for,
- only partial exchanges permitted,
- topology often is not exchanged and may have to be rebuilt,
- attribute information is often handled separately.

Most data exchange to date has concentrated on the graphic component since this has traditionally been the prime focus of most applications. Attribute information is often handled by the exchange of ASCII text files. While this is a simple approach, the files are often large and information on how the attribute information is to be handled must be provided external to the data itself. Data exchange often requires a great deal of knowledge and expertise by both the sender and the recipient of both the generating system and the receiving system.

Data Exchange in Canada - Provincial Activities

Exchange formats referenced under activities are discussed later in the paper.

British Columbia - the format defined in Alberta (DMDF) has been adopted and modified for use with the local provincial mapping program (TRIM - Terrain Resource Information Management) and is known as the MOEP format. At the initiation of this study, a new format had been proposed for use in British Columbia, known as BC-SAIF (British Columbia Spatial Archive and Interchange Format). This format is based on concepts associated with the United States Spatial Data Transfer Specification (US-SDTS).

Alberta - In the province of Alberta, the major supplier of digital mapping data is the Land Information Services Division (LISD) of the Department of Forestry, Lands and Wildlife. Currently, they provide information using three formats: IGDS, Intergraph's proprietary graphics format, ISIF, Intergraph Standard Interchange Format, DMDF, Digital Map Data Format. LISD is also, at the current time, endorsing and adopting CCOGIF (Canadian Council on Geomatics Interchange Format) and may in the future use this in preference to the three previously listed formats.

Saskatchewan/Manitoba - very little has been decided in these two provinces regarding data exchange. The issue is currently being investigated.

Ontario - In Ontario, MDIF (Map Data Interchange Format) is being promulgated for use by the Ontario Ministry of Natural Resources. Technical specification for this format has recently been released for public review and for those wishing to implement encoders or decoders. It appears that MDIF will be the prime exchange format in Ontario.

Quebec - limited data exchange has occurred in Quebec due to the lack of readily available data to distribute. Tentative steps are being taken at the present time to use or to evaluate the use of CCOGIF for data exchange in Quebec.

Maritimes - at present, most data exchange occurring utilizes vendor host formats (CARIS is typical), versions of DLG (Digital Line Graph), and in some cases MACDIF (Map and Chart Data Interchange Format).

Data Exchange in Canada - National Activities
Inter-Agency Committee on Geomatics (IACG) - consists of eighteen Federal Agencies structured so as to have a Steering Committee, a Main Committee, and six Subcommittees dealing with GIS data models, communication and networking, federal data bases, GIS standards, research and education, user needs and applications. The focus is on cooperation between various federal government departments.

Canadian General Standards Board - as an outgrowth of the IACG, the Standards Council of Canada has assigned to the Canadian General Standards Board the task of developing a number of national standards in the area of geomatics and GIS. This has led to the Committee on Geomatics whose aim is "to develop and adopt standards for the sharing of geomatics data". A number of sub-committees have been established to deal with data transfer and interchange, data modelling, feature classification, and data dictionaries and cataloguing.

Canadian Council on Geomatics - previously called the Canadian Council for Surveying and Mapping, it has undertaken standards activities relating to topographic features and data exchange for a number of years. In 1984, they produced a dictionary of topographic features. In 1986, a Digital Topographic Information Model was produced. An exchange format was released for testing with the provinces in 1988 and revised in 1989. Draft specifications for a national topographic database was released in March of 1989.

MACDIF Project - the Ontario Ministry of Natural Resources, Five Canadian Departments including the Canadian Hydrographic Service, and the United States National Ocean Service sponsored the development of a specification for the telecommunications of map and chart data. This effort is known as MACDIF (Map And Chart Data Interchange Format).

Joint International Efforts
International Cartographic Association (ICA) - established a Working Group on Digital Cartographic Data Exchange Standards on August 17, 1989 which currently consists of twelve countries. Its initial goals are to allow for a mechanism by which information and reports by member countries concerning the development of digital cartographic data exchange standards may be collected and distributed to member countries, to act as a focal point of information concerning digital cartographic data exchange developments throughout the world and to identify research needs that arise from the standards process. Initial goals do not include the drafting or implementation of any international standard for data exchange.

International Hydrographic Organization (IHO) - two committees were organized by the IHO. One, the Committee on Electronic Charting (COE) formed three groups, a data base working group, a colours and symbols working group, and a chart updating working group. The second committee organized by the International Hydrographic Organization was the Committee for the Exchange of Digital Data (CEDD), which concerned itself with an actual exchange format, features and objects definition, and terminology.

Digital Geographic Information Working Group (DGIWG) - consists of eleven countries, it has a panel of experts, a steering committee chaired by the United Kingdom, and a technical committee chaired by the United States. This group released a final draft of an exchange standard in February 1989, a draft Feature/Attribute Coding Catalog in 1987 and drafts of various raster graphics specifications in March, 1988. This group was formerly part of NATO activities.

GIS Related Data Exchange Standards/Formats
BC-SAIF: British Columbia - Spatial Archive and Interchange Format. A new format proposed in British Columbia to replace the MOEP (or TRIM) format. It is based on the new United States format (US-SDTS) and meant to incorporate modern concepts and principles. This format will be similar to the United States format. Feature classification within this format is provided via a hierarchical feature coding scheme similar to the one defined for CCOGIF.

CCOGIF: Canadian Council on Geomatics (CCOG) Interchange Format. This format was previously referred to as the CCSM format, from Canadian Council on Surveying and Mapping, the previous name of CCOG. CCOGIF was designed for the exchange of topographic data and was built upon a sequential tape storage format. CCOGIF allows for extensive header information including data capture information, data sources, accuracy (global), projection and referencing information. The format allows for a logical volume to consist of more than one physical volume (i.e., tape) with volume directory information being repeated at the beginning of each physical volume. This format has provision for circular arcs and ellipses. All coordinate data is handled as 3-D absolute coordinate data with ASCII characters used to encode each value in a coordinate triplet. Attribute information is allowed for as well as spatial relationships (topology). Topology consists of connected nodes and left/right areas for lines. Feature classification is an important aspect of CCOGIF. The feature classification scheme is hierarchical in nature with a fixed 10-digit alphanumeric code. This format does not handle raster or grid data.

CEDD-STF: Committee on the Exchange of Digital Data - Spatial Transfer Format. Fifteen countries, including Canada, met to produce an exchange format which would also have the ability to perform electronic charting. The format would be usable by both naive and sophisticated users. Test data for the format was distributed in 1985 with the actual description of CEDD-STF released in 1986. CEDD-STF uses a fixed field ASCII format throughout. Attributes present have a fixed position in a list of possible attributes. Most attributes are numerical representing textual descriptions. Classification consists of a three-level fixed hierarchy with most features being those found on charts. Global information such as data quality is allowed. This specification allows for both free or spaghetti type vectors and chain-node topology vector representation (the topology deals with shared segments). Data sets cannot exceed more than one volume and information available seems to indicate that magnetic tape is the preferred medium. There is no capability for raster or grid data. The development of this format is no longer active.

DLG: Digital Line Graph. This format was initially developed by the U.S. Geological Survey (USGS) as part of the U.S. National Mapping Program Digital Cartographic Data Standards. It was and is used to distribute USGS digital maps. This format is file based in structure. There is a limited amount of header information; the specification of projection information is possible as well as global data quality. The encoding of graphic objects such as ellipses or circular arcs is not supported. There is no unique identification of objects. Topology may be specified and feature classification is possible with a seven digit specification. The DLG coordinate space is 2-D with coordinates being stored to 12 digits precision (absolute values). This format does not support raster or grid cell data. DLG is often modified by various vendors or agencies to be able to handle additional topology, 3-D coordinates, and attribute information. Latest information indicates that a new version of DLG is being prepared, known as DLG-E (Digital Line Graph - Enhanced).

DMDF: Digital Map Data Format. DMDF was developed to support the Alberta government's 1:20 000 digital base mapping project. While it was designed and implemented strictly for a specific project, its use expanded beyond this due to the lack of any other exchange format being readily available. The DMDF format is easily understood and can be implemented rapidly in a minimal computing environment. DMDF was later adopted as the basis of the MOEP format used in British Columbia. DMDF has the capability to handle a basic set of cartographic objects; associated with each object or element is a 10 character feature code based on the CCOGIF feature classification system, with additions for local provincial concerns. DMDF is ASCII-based with fixed fields. Coordinate data is 3-D; the X- and Y- coordinate fields are 10 digit precision and the Z- is 8 digit precision. Point objects are used to represent cartographic symbols with a scale factor. Minimal header information is passed with each exchange file. Raster data is not incorporated into this format.

MACDIF: Map And Chart Data Interchange Format. MACDIF is a comprehensive interchange standard orientated to the telecommunications environment. It handles both topographic map and hydrographic chart data and has been proposed as a basis for both national and international standards. MACDIF is built upon a number of other standards, an important one being ISO's Open System Interconnect (OSI), which provides a layered architecture for data communications. MACDIF has been designed to support all written human languages. It is structured as a data grammar using Abstract Syntax Notation (ASN.1). MACDIF has extensive header information which allows for blind interchange of data as well as making the format suitable for archival purposes. Feature classification is not predefined in this format, but is left open for the user to define as desired. Coordinate space is either 2-D or 3-D; precision is variable. One significant difference of MACDIF to most other formats is the ability to encode coordinates as either absolute, relative, or via incremental amounts. The current specification provides for raster or grid data capability, but this aspect has not been explicitly defined as yet. MACDIF has been designed with the idea of being able to update portions of an existing data set. This could be sub-areas or specific features.

MDIF: Map Data Interchange Format. MDIF is the format being developed and promoted by the Ontario Ministry of Natural Resources (OMNR) and is similar to MACDIF. MDIF has some extensions to MACDIF and is more object oriented in approach. Most comments concerning MACDIF are also relevant to MDIF. Unlike MACDIF, MDIF has explicitly provided a definition for raster, grid, and point data. MDIF can handle both structured (explicit topology) and non-structured data.

MOEP-STF: (British Columbia) Ministry Of Environment and Parks -Spatial Transfer Format. The MOEP format is an enhancement of the DMDF format developed by the Province of Alberta. This format is primarily intended for the exchange of 1:20 000 digital topographic and cadastral data. Most comments which appear and are associated with the

DMDF format are applicable here. Significant differences between DMDF and MOEP are the provision of circular arcs, explicit alphanumeric (textual) attribute records, and construction lines. The addition of construction lines, lines which convey information but are not part of the actual data, provides a mechanism to exchange polygon data.

SA-STF: South African - Spatial Transfer Format. The South African standard is based on a relational model (i.e., relational tables are exchanged). In SA-STF, a data set being exchanged consists of two physical files. The first file, File Identification, is a fixed format file consisting of human readable ASCII characters describing the data. The second physical file contains the Global Information Section and a number of Geo-Referenced Information Relations sections. The Global Information Section contains details of the data being exchanged (e.g., projections, coordinate systems, units, etc). The Geo-Referenced Information Relations sections contain the actual data being exchanged. It consists of a number of relational database tables. Relations are specified to link features to their classification and spatial attributes (position) as well as data quality and definitions of the classification and attribute schemes. The standard allows for circular arcs, regions, matrix objects, and raster, as well as compound features. SA-STF allows for two types of topological relationships, coincidence and exclusion. It does not handle the containment of points or lines in areas or the intersection of lines or areas.

UK-NTF: United Kingdom - National Transfer Format. This format allows for vector data to be transferred either unstructured or structured, with few or many attributes. The format allows for extensive header information and quality information at four levels: overall database, the section, the feature, and the coordinate. Coordinate space is 2-D or 3-D. There is provision for both a default and optional data dictionary as well as a feature class dictionary separate from the default data dictionary. This transfer format focuses on topographic features to the exclusion of others (e.g., thematic, hydrographic, etc.). Raster data is allowed for in 2-D or 3-D and can be encoded as simple matrix, run-length, as well as other more complicated schemes. The feature classification scheme is hierarchical in nature. To aid in the definition of topology, invisible (construction) lines are defined. Topology is mainly concerned with connectivity.

US-SDTS: United States - Spatial Data Transfer Specification. US-SDTS covers both vector and raster data. It supports 0, 1, and 2 dimensional elements (points, lines, and areas). A very large range of spatial entities or objects are allowed for. Vector data may be structured in either a relational or hierarchical manner for exchange. The format breaks down high level components into a set of modules that can be looked at in a semi-relational manner. The modules can contain: global information - cataloguing, identification, security, spatial referencing, spatial domains, data dictionary, transfer statistics; data quality - lineage, positional, attribute accuracy; spatial data - can be referenced in vector form, relational form, raster form. Feature classification used is of the linear list type. Extensive topology is allowed for including topologies of: adjacency - left and right areas on chains; coincidence - spatial attributes shared; exclusion - areas contained by other areas. US-SDTS allows for data sets to be defined over multiple volumes. This format is not restricted to any hardware platform or media. It uses ISO 8211 as the base for encoding the data to be transferred. ISO 8211 is a file structured data standard and the US-SDTS uses multiple files to carry different information on a data set. This format is very broad in scope and is having a major influence on exchange standards worldwide. Its influence is affecting Europe, the United Kingdom, Japan, Australia, the IHO, and many GIS system suppliers. Note that there are indications that this format has changed substantially from the description appearing in the January 1988 issue of the American Cartographer.

Associated Data Exchange Standards/Formats
In addition to the previously discussed formats, other associated exchange standards or formats are being used to exchange map data. These include: DIME - Dual Independent Map Encoding (developed in the early 1970's by the U.S. Bureau of the Census for the storage of geographically related census information); DXF - Data eXchange Format (a CAD orientated exchange format proposed by the manufacturers of AutoCad); IGES - Initial Graphics Exchange Specification (developed as a neutral format for the transmission of computer representations of engineering drawings between dissimilar CADCAM systems; ISIF - Intergraph Standard Interchange Format (developed by Intergraph Corporation as a means to transmit graphics and associated data); Mini-Topo (a potential format being developed by the Defense Mapping Agency (DMA) in the United States for the distribution of their data); TIGER - Topologically Integrated Geographic Encoding and Referencing (developed by the U.S. Department of Commerce and is meant to be used as a digital map base to support the activities of the Census Bureau).

Other exchange formats not being developed for the exchange of map or cartographic information utilize many of the same concepts. These include: CGM - Computer Graphics Metafile (used for the exchange of graphic images between different types of display devices); EDIF - Electronic Design Interchange Format (used for exchanging design information and for 'design to/from foundry' communications); ODA/ODIF - Office Document Architecture/Office Document Interface Format (being developed to exchange documents specified with raster graphics); PDES -Product Data Exchange Specification (is the result of activity by the US National Bureau of Standards and the International Standards Organization (ISO); SET - Standard d'Echange et de Transfert - Data Exchange and Transfer Standard (a development effort by Aerospatiale and the European aerospace industry; STEP - Standard for The Exchange of Product data (an international standard which is currently being discussed and which will be an outgrowth of VDA-FS (a German standard being developed by the automotive industry), SET, and PDES.

Exchange Formats - The Vendor Aspect Forces which impel vendors to implement various formats tend to be

client or market related as clients insist that a format be present for a system sale to be completed or in order to complete a project. Implementations are often minimal in nature, with those components of a format which are critical to a given project or client implemented and others left for another time. Often there is poor consistency between vendor implementations. In addition, most vendors implement software to import data, rather than export it. Reasons for this are that the import of certain data is necessary to complete a project, and that it is in the interest of a vendor to allow for data to be imported into the system, rather than out (providing mechanisms for putting data 'into' the system tends to make the system more useful and functional).
An analysis of information from 56 vendors, with a total of 267 import and/or export modules provides the following table:

FORMAT(S)	OCCURRENCE (as percentage of total conversion modules)	OCCURRENCE (as percentage of total vendors)
DLG	14.6%	70%
DXF	13.1%	62%
ISIF	10.1%	48%
DIME, IGES	4.9%	23%
TIGER	4.5%	21%
DEM	3.4%	16%
IGDS	2.6%	13%
ASCII, ERDAS	2.2%	11%
LANDSAT	1.9%	9%
ARC/INFO, ELAS, ETAK, MOSS	1.5%	7%
Remaining formats	≤1.0%	≤5%

Note: ASCII refers to miscellaneous ASCII based grid/cell formats; LANDSAT, properly speaking, is not a format but was referred to in this manner in various vendor literature.

From the table, it can be seen that a large number of vendors have implemented some level of support for a small group of 'core' formats. It appears that DLG is the most frequently supported format closely followed by DXF. DLG's strength comes from the fact that a large amount of U.S. government data is distributed in this format and most vendors are U.S. based. This implies that government can play a strong role in guiding standards adoption by simply providing and requesting data in a given format. DXF's strength comes from the wide use of AutoCAD. A format widely available becomes a format widely used. While a number of vendors support DLG and it seems this would be a likely solution to many exchange problems, there are often incompatibilities between software implementations. Different vendors implement different versions without indicating which, or will only implement a portion without indicating which portion, or will modify the DLG format to better handle the vended systems internal data structure.

Data Exchange Standards - Trends and Issues
There is an obvious trend in GIS data exchange standards, nationally and internationally, to automate the exchange process as much as possible ('blind' interchange). This is leading to much more complex specifications and associated computer software. An additional trend appears to be an object orientated approach to feature/object definition rather than a segmented approach as in the past.

Recently the concept of a Geographic Document Architecture (GDA) has been proposed which organizes data into components called Content Architectures. This is similar to the concept of Office Document Architecture (ODA). GDA supposes that with many different standards for GIS interchange coming into existence and with there being little chance of convergence, some mechanism which separates content and carrier be devised. For each content type, a Content Architecture would be developed. For all Content Architectures, the same data coding and encapsulation techniques would be used.

Topology and the representation of topology has not been settled. It is an issue which is still being discussed. There is no general consensus as to the best way to handle this.

Data Exchange - Organizational Strategy Considerations
The GIS data exchange standards process is long and slow, even to the extent that upon completion, an original standard may possibly be out of date. During the standards process it is important for an organization to develop a strategy for the exchange of GIS data. What would a good strategy be? Does the strategy manage future change? Does the strategy manage risk? How are local immediate needs, national trends, international trends, and future needs taken into account by the strategy? Data exchange strategy raises questions which may have no simple answer. An organizations strategy depends upon its unique circumstances internally and the manner of data exchange which must be accommodated for.

Conclusion
In the course of this study it has become apparent that the issue of GIS related data exchange is broader and more complex than may first appear to be the case. In fact, it is approaching a point where a substantial amount of base knowledge is required to understand and appreciate all of the interrelated issues. The development of standards requires its own standards with recommended practices and guides; there is a need to establish criteria for adopting standards and procedures for implementing those standards. With regard to standards it is hoped that consensus in a timely manner will be reached, but, in the development of standards, interests do not always coincide and consensus can be difficult. Above all, the specifying of a standard is an on-going process.

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A more complete discussion of the issues raised in this paper and more complete reference list may be found in the Alberta Research Council Technical Report **Geographic Information Systems: Data Exchange Standards and Formats**, September 1989. Selected references follow:

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Creation of a Forest Inventory Database Using Airborne Digital Imagery and GIS

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Abstract

The management of forest resources requires timely and accurate information in a format that can be easily interrogated for decision making purposes. Recently, advances in the field of Geographic Information Systems (GIS) and their computer platforms have provided tremendous power for those involved in forest management. Much of the cost of commissioning and operating a GIS is related to the development and maintenance of the desired database. For forestry applications, recent advances in the fields of airborne multispectral digital imaging and airborne image registration offer great promise in reducing the costs associated with digital data capture and subsequent updates on a cyclical basis.

High resolution MEIS (Multispectral Electro-optical Imaging Scanner) imagery was acquired over an area equivalent to 10 Ontario Base Maps (OBMs) covering 1000 square kilometers. Data from eight multispectral channels was recorded on high density tape at a ground resolution of 5 meters. Aircraft navigation system data was also recorded for use in the subsequent geometric correction and registration of the data.

A 200 square kilometer subset (2 OBMs) of multispectral data was compressed using principal component analysis to reduce data volume. Subsequently, the imagery was geometrically corrected to a UTM map projection and parallel flight lines were mosaiced to produce the desired coverage. The imagery was classified using supervised classification techniques and output to a single channel raster image file. The classified raster file was converted to a vector coverage on a GIS. Polygon coverages were created and attributes (species, maturity, stocking, etc.) were assigned to each polygon.

The new database was interrogated and compared to existing Forest Inventory data for both cartographic and species accuracy.

Session C8
Management Issues and Perspectives in GIS

Implementing GIS Technology in a Forest Inventory System

Implementing the Corporate GIS

Progress Through Cooperation: Alberta Vegetation Inventory

Development of an International GIS at Boise Cascade

GIS'90 Symposium

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Implementing GIS Technology in a Forest Inventory System

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Abstract
Four years ago, the Western Wood Products Division of Potlatch Corporation purchased a geographic information system. Initial implementation objectives focused on a stand based in-place inventory to support resource operations within the company. The initial system design identified four implementation stages: 1) compiling an accurate, centralized database of essential map features and attributes; 2) developing transaction based software applications to maintain the database; 3) decentralizing access to the resource database through menu driven map and report generation systems; and 4) providing analytical capabilities to evaluate management alternatives. The first three stages have been successfully completed for forest inventory applications. However, patterns of system use and methods to distribute resource information are different than anticipated. With transaction and reporting capabilities established, stage four implementation will develop techniques to evaluate spatial constraints to forestry and logging operations.

Introduction

GIS implementation: what makes it work? No single factor provides a simple answer for all organizations. Most likely, no common collection of factors apply to every organization transferring the technology within its management structure. However, organizations can communicate their system implementation experiences in order to provide opportunities for others to consider the facts, and define their appropriate path through the system implementation maze. This paper is presented in exactly that context: to document GIS implementation experiences at Potlatch Corporation, not as a final solution for your particular organization, but as an option for the reader's evaluation.

Forest Inventory Framework

The GIS was purchased to support an existing in-place forest inventory system. The technology was new and different, but the objective was to incorporate the technology as a component of the inventory system, as opposed to implementing a stand alone technology to support independent projects. The technology of GIS integrates inventory related map features and their associated attributes into a single, manageable database.

The Potlatch inventory system delineates timber stands as operable management units with single prescriptions. The average size of the inventory stand is 150 acres; the size, however, ranges from 10 to 500 acres. Each stand boundary also defines a sampling unit for an in-place cruise. A forester allocates plots within the stand boundary, records tree measurements for the individual plots, and also records stand characteristics.

Plot data are processed to create a stand table specific to the delineated stand. Additional processing aggregates stand table data to stand level estimates of volume and tree size classes per unit area.

Inventory software systems involved in this process include cruise processing, a log merchandiser, and two growth projection systems.

Accurate Map Database

An in-place inventory requires accurate map information to delineate and subsequently locate timber stands. The cruise provides the tree measurements to estimate volume by end products; the map feature identifies the location of that estimated volume. In addition to the locational information, the map database also provides the area estimate for each stand. Stand level volume estimates are calculated by expanding unit area estimates of volume (volume per acre) with the area measured from the stand polygon. The map database is the source of stand area. Accurate location of planimetric map features and ownership lines is essential.

To provide an accurate estimate of location and acres, a planimetric mapping project was initiated to prepare new base maps. Planimetric features compiled from 1:80 000 high altitude photography were roads, ridge lines, hydrology network, mountain peaks, saddle points and cultural features. On mylar plotted basemaps, field identified survey corners were transferred from orthophotographs to the base maps. Public land survey lines were manually drafted using existing survey records and the transferred survey corners.

The roads, ridges, streams and ownership lines established the templates to delineate the timber stand boundaries. These boundaries were drafted, digitized and processed to calculate stand acreages.

The stereoplotter compilation of planimetric features and the table digitizing of ownership and stand lines were contracted out by Potlatch. Inventory systems staff compiled map features which could not be interpreted from photography and performed audits of the delivered products. Contracting in this manner minimized in-house staffing and equipment requirements, allowed time for system design, and produced a planimetric database which satisfied accuracy specifications.

The mapping project included 2.2 million acres in northern Idaho; the duration of the project was approximately 30 months.

Transaction Database

While the mapping project was in progress, forestry and logging operations continued. When the mapping project ended, the newly created digital database was out of date. New roads had been constructed, land ownership had changed, timber stands had been logged, and foresters had delineated and cruised stands.

In order to support the reporting requirements of operations staff, major system applications were designed to update the database due to the changes which had occurred and will continue to occur every year. These applications record transactions to fundamental database entities such as roads, land ownership, and timber stands.

Previous manual systems were time consuming and out of date by as much as ten years. Inventory updates, for example, were typically completed 18 months after submitted. With the transaction based system, the land department submits ownership changes four times a year; the foresters identify inventory updates three times a year; and the new roads are compiled once every two years.

Supporting the transaction level database has become a major application of the GIS technology at Potlatch.

Decentralized Database Access

Access to inventory data was a major implementation objective. The transaction level database administration has been centralized, but the access to the data has been decentralized through menus written as part of new system applications.

Development of new system applications is an ongoing process, often involving expansion of the map database and the addition of new attribute databases. The application development process adopted at Potlatch is the method which defines database access and reporting requirements

The end user group initiates the system design process under the guidance of the user coordinator. It is the end user who identifies system requirements and communicates those requirements to the software design team.

The design approach assigns responsibility appropriately. The user defines requirements, divorced from the technology, for operational problems. The design team writes software to support the applications as specified by the user group. Real problems foster tangible solutions.

Analyzing Management Alternatives

The first three stages of implementation have involved over four years of effort. The database exists, transaction processing is in place and functional, and management reporting of map and attribute data through menus provides access to a variety of Resource Department staff. All three stages are a prerequisite to the analysis of management alternatives.

This year, the system will be applied to evaluate spatial constraints to harvest schedules. In a mixed ownership operating area, with pressures to meet timber demands, the importance of water quality and other considerations is increasing. Applications will be developed this year to test alternative short term harvest plans to meet harvest objectives within constraints of stand size and spatial distribution of the cutting.

Patterns of System Usage

Four years ago, the inventory systems staff planned to replace paper map files with electronic media. Under this scheme, current map information would always be available via the terminal. The success of this approach was marginal.

Resource Department staff were accustomed to instant access; maps were copied and stored in file cabinets. Accessing terminals and drawing the map on the screen was an additional step which interfered with their work. In addition, users of map information required scale controlled maps with high cartographic quality and detail. Screen were not acceptable replacements for high quality cartographic products.

The system is now used to maintain a variety of map products which represent the full range of forest management levels in the organization. As transactions occur, the update process creates revised map products which replace the outdated maps in the file cabinet. The important result is that the accurate new map database is now in use and the information has been successfully distributed to the resource staff. GIS technology supports this activity through electronic publishing and the integrated management of a transaction level map and attribute database.

Summary

GIS technology has been successfully implemented in the Resource Department at Potlatch Corporation. The technology was integrated into an existing stand level forest inventory system. Significant effort and expense were invested to develop an accurate planimetric map database derived from photography. The accuracy has important consequences for estimating and locating the timber resource. Early software development activities implemented transaction level database management functions. This capability was essential to maintain the inventory database for the intended user community. Access to the data is decentralized through menu applications defined by user groups within the company. The stand level inventory, the map database, and transaction processing establish the building blocks for future system applications which will evaluate management alternatives.

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Implementing the Corporate Geographic Information System

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Abstract
Geographic information systems (GIS) are being widely used by the forest products industry and government forestry agencies. However, few organizations are developing their GIS as corporate information systems. In this paper, the author discusses the concept of a corporate GIS, its use as a decision support tool and some of the aspects of planning for its implementation.

Introduction

Geographic information systems (GIS) have been in use in the forest products industry for about 10 years. Efforts to date by governments and forest products companies have largely gone into hardware acquisition, software implementation, and data base creation. The principle focus has been on producing the conventional information products faster and better. With more widespread use of GIS, decision makers and professional foresters are beginning to recognize its potential as more than just a mapping tool. It is becoming recognized that if GIS implementation is to fully justify its cost, it must be better linked to decision making. There must be better integration of GIS technology with the workings of the corporation to obtain larger benefits.

At GIS'89, the results of a study performed by the Nordic Countries (Denmark, Finland, Iceland, Norway, and Sweden) through the joint project NORDISK KVANTIF, were presented (5). It was determined from a review of GIS implementation around the world that returns on investment ranging from 1:1 to 4:1 could be obtained from GIS implementations depending on the approach selected. A return of 1:1 could be expected from the automation of basic mapping and drafting functions. Returns of 2:1 could be obtained when GIS was applied to problem solving and planning activities. The highest returns could be obtained from centralization and collective use of data bases common to all users, returns on investment of 4:1 were attainable. The study further concluded that no specific systems or software delivered better profitability than any others and that the main factors in profitability were related to the organization, cooperation, available technical skills, and the approach to implementation selected at the outset.

Creating and maintaining shared corporate data bases implies better integration of GIS into the planning and administration functions of the corporation. Some of the aspects of designing a corporate GIS and the inter-relationships between data, technology and organization will be discussed in this paper. Some of these aspects are well developed and understood, others are still being explored. We will look at three main elements: GIS as a decision support tool, information handling in support of decision making, and planning and project management for successful implementation.

GIS as a Tool to Support Decision Making

The term GIS has come to be defined and understood in terms of functional techniques and tools, as seen in Peter Burrough's definition of a GIS: "a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes" (2). Although his definition highlights the technological aspects of GIS, it also stresses procedures, without reference to specific purposes. Fisher, in his review of information technologies as applied to geographic information, defines a GIS as: "the management, analysis, and manipulation of spatially referenced information in a problem solving synthesis" (3). And in B.C., the Terrain Resources Information Management (TRIM) project emphasizes the analytical nature of a GIS, defining it as "a set of tools designed to support the planning and decision-making functions of an organization" (1).

Each of these definitions implies integration of GIS with the decision making activities of the corporation. To manage, the forest manager makes decisions about the choice, location and timing of management interventions that control the future forest. To do so, the manager works from forecasts based on current data and trends observed for similar interventions. The inherent capabilities of GIS to create a computer model of the real world permit the user to explore various management options (scenarios). The user can then select the best-suited scenario for implementation. In this manner, GIS can be effectively applied to problem solving and decision making.

However, for the GIS to be used in this manner, accurate, explicit descriptions (models) of the workings of the corporation must be created. The user must develop an in-depth understanding of the potential of GIS as a decision support tool and GIS implementors must develop thorough understandings of the processes to which GIS is to be applied. Effective communication between end-users and implementors is essential.

To date, efforts to apply GIS to decision making have occurred primarily at the operations level and as separate tools often working from separate data bases. Examples include using GIS for cut-block layout and road design. Integration of GIS with corporate functions and decision making models operating from shared data bases has not yet occurred. The elements of a corporate, integrated decision support tool have been conceived, but considerable work is required before one can be implemented.

A current project by the Ontario Ministry of Natural Resources to develop a forest management decision support system has identified some of the basic elements as:

- a comprehensive land and resource data base,
- interpretive and derivative models to classify data for various land analysis purposes,
- predictive models to deal with the impacts to the forest from management intervention,
- mechanisms for considering alternate land uses and land administration policy,
- models for interpreting and integrating market factors, and

supply and utilization models that account for mill requirements and capacities.

Although there are some scientific and technological challenges that need to be addressed to make the concept a reality, the larger challenge lies in accurately describing the natural and administrative processes that comprise forest management decision making and to design and implement cost-effective systems within the corporate context that meet defined decision making requirements.

Information Handling and Decision Making

Different levels of the corporation are responsible for different types of decisions. Business policy and planning levels make investment and resource allocation decisions related to products, mill capacities and expansions. They create marketing strategies based on demands and available products. They analyze the various aspects of the corporation to determine the profitability of forest operations. Strategic planning processes deal with planning and managing the forest resource over the long term, including management planning, management inventory, silviculture planning, and long range planning for operational needs such as roads. Strategic planning provides estimates of the impact of current practices on future timber supplies and environmental factors. The operations group manages and coordinates functions related to bush operations. Large amounts of administrative information are collected and maintained. These include wood inventories, harvest production and costs, bush inventory, wood deliveries, silviculture production reports, road construction data, contractor production, and vehicle utilization. The operations group also performs site specific planning for harvest area layouts, roads location, and annual operating plans. On-site silviculture is also usually managed by the operations group including performing regeneration surveys, scarification and site preparation, planting; seeding; thinning, herbicide application, and free-to-grow surveys. Operations groups may also collect and maintain growth and yield data from permanent sample plots.

Each management activity requires specialized information often arising from complex analyses. However, most of the data required to derive the information originates within the corporation resulting from day-to-day activities of the corporation's staff. Currently, these activities are related through the formal reporting and informal communication mechanisms of the corporation. An integrated corporate GIS should reflect current information handling practices and facilitate the collection and communication of the data required to support decision processes. In other words, the GIS should be fully integrated with the day-to-day workings of the corporation. And the data created from the day-to-day functions of the corporation should be captured at source for use in decision making by other parts of the corporation.

It is broadly recognized that in GIS implementation, data related activities are the main source of cost. It is also well accepted that significant savings can result from reducing the number of times a piece of information must be handled. Additionally, costly problems arise when different parts of the corporation collect the same information inconsistently and then apply those different versions of the information to decision making. Part of the focus for the corporate GIS is therefore to increase the efficiency of data handling and to make the right information more readily available for decision making.

Different parts of the corporation from operations management to strategic and business planning require different information in support of their decision making. However, a single data base and maintenance process may support all three levels. Only the analysis and reporting functions need differ. This does not imply that all the data need reside in one physical data base, or that individual users need to have all the corporation's data available to them. However, only one data model exists for the corporations geographic data, and all data conform to that model.

Data bases should be designed so that they are maintained by capturing records of the day-to-day activities of the corporation. To facilitate efficient collection of the data, hardware and software must be distributed to where the work is being performed. To ensure that data are collected in a consistent manner, standard procedures and a comprehensive data base design must be implemented. Given the complexity of the task, a full-time data administrator should be employed.

The importance of analyzing the information flows of the corporation both as they exist and as they could be, becomes central to successful information management.

Implementation Planning

GIS has that immediate high technology appeal that is associated with computer graphics and there is a strong tendency to focus on the technology. Many companies and government agencies begin GIS implementation by purchasing hardware and software (4). However, the problem-solving orientation of our GIS definition points to the need to direct attention to the organizational context in which the problems exist. As was discussed in the previous section, the most significant gains in efficiency and effectiveness come from appropriately matching technology and data to organizational functions. Therefore, it is the organizational context, and not the technology, that assumes the greatest significance in planning GIS implementation.

There is a growing recognition of the importance of planning and that implementing a GIS is not as simple as buying some hardware and software and loading your forest inventory into it. Most organizations are following the typical steps in the process of defining requirements, exploring alternatives and benefits, developing specifications and a design, acquiring GIS technology and finally implementing the selected system. The complexity of implementation planning varies with the size and complexity of the corporation and the functions to be supported.

Planning and implementation has stressed providing specific tools for specific functions in the organization. Computer-aided mapping in the drafting department. Road and harvest planning for the operations forester. Forest inventory data are collected and maintained by a central group traditionally responsible for forest inventory, usually according to a regular cycle. Data are loaded to 'stand alone' GIS to support specific activities with more attention paid to immediate outputs than to data administration. Far less frequently does GIS development occur within the context of a corporate information management strategy. Although many corporations are doing implementation planning for GIS prior to buying a system, most are dealing with GIS requests on an unit by unit basis leaving integration to be dealt with later. The potential for using GIS as a decision support tool is recognized, but planning for it is lacking.

Three main components which must be considered are the data, the technology, and the organizational context. Corporate implementation planning consists of establishing effective relationships between these and ensuring that each matches the others across the organization. This is relatively straightforward in small organizations with a few centrally located users and small data bases. It becomes more complicated as the number of users and functions increases.

In larger companies and government agencies, the management and operations functions are spread across many organizational units, frequently in different geographic locations. Successful implementation results from striking a balance between standards and centralized planning, and distributed implementation that can benefit from local ingenuity. Participation by the end-user as the system designer is critical to building commitment and developing accurate implementation specifications. The different levels (operations, planning and senior management) need to be viewed as distinct and separate users working within a common context. The project is managed as a multi-participant project even though all the functions being analyzed exist within the same corporation. Each set of requirements is analyzed separately and then combined to determine opportunities for gains in efficiency and the extent to which autonomy within individual organizational units can be supported. This process produces a model of the information flows in the organization which is then translated into a technical design. Aspects of the corporation's work become implemented as separate subsystems, following consistent design standards, integrated within networks, to create corporate systems. The GIS becomes part of the corporation's management infrastructure.

The design and implementation of corporate GIS is still developmental, but work to date indicates the following to be significant aspects of the planning process.

1) The first step is to define and agree upon the process to be used and the long range goals for GIS implementation. These should be matched with business planning objectives. The plan, the goals and the resources required for planning should be publicly committed to by senior management.

2) The corporation's functions at all levels (business planning, strategic planning, and operations planning and management) should be analyzed and the inter-relationships between them identified. Each of the functions should be assessed in relation to the goals for the corporation and the GIS, to determine relevance and priorities.

3) For each of the identified functions the information requirements, sources and handling processes should be identified. The result should be an information flow model indicating the origin, processing and end use of all the corporation's information. The model of the existing information flow should be reviewed in the context of how things might change with the implementation of a GIS and where and how the data will be captured and maintained.

4) Based on the results of the first three steps, an information resources management strategy should be prepared. It should identify functions to be supported, information handling processes for information collection, analysis and maintenance, and the priorities for automation.

5) Once the organizational context has been determined, a general technical design can be developed and a technology strategy can be prepared. Part of this strategy will be to locate the technology within organizational units and to determine new inter-relationships and job functions as necessary. Technical specifications for hardware and software acquisition are then prepared.

6) An organizational change and technology transfer strategy can now be developed, having identified those organizational units that will be impacted by the GIS. General training plans, roles and responsibilities for organizational units can be developed and long range budgets determined.

7) Finally, within the context of the corporate strategy, specific implementation plans, budgets, and training schedules can be prepared for each of the organizational units.

Conclusion

A corporate approach to GIS means that all GIS uses are considered within a single context and that the relationships between different parts of the corporation are understood and optimized. Central to the corporation's functions is decision making. Decision making occurs at various levels from senior management to bush operations. The information required to support the decisions varies, but the source of most of the required information is the corporation. Mechanisms to capture, manage and distribute the data to its required location for decision making need to be implemented. This concept is well understood in the design of management information systems (MIS); it now needs to be applied to GIS to make it more cost-effective.

A GIS can be designed to support the decision making processes of a corporation if all of the information handling is defined. Applying GIS to decision making can make professional and support staff more effective at their jobs. More time can be devoted to analysis of problems and less on the basic information collection, compilation and presentation. However, if the GIS is developed in isolation, as a separate tool with separate data bases that must be loaded and maintained in isolation from the day-to-day workings of the corporation, GIS will not be cost-effective. Many large organizations are going through the process of cost justifying GIS. Individual uses of the GIS are examined, but most frequently as stand-alone systems. Many benefits of GIS implementation are missed because the corporate context is not considered. The cumulative value of continuous data collection, records management and information analysis is missed.

The answer to making GIS more cost-effective is in part, to apply it to those aspects of the corporations activities that are the most expensive and important - decision making.

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Progress through Cooperation: Alberta Vegetation Inventory

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Abstract
Alberta is designing and implementing a provincial vegetation inventory system to meet the information requirements for the management of resources including timber, wildlife habitat and rangelands (grazing). This multipurpose resource inventory utilizes the latest GIS technologies to provide information products to the resource managers. Inter-agency cooperation in data collection, digital mapping and information management offers considerable cost savings while promoting inter-agency consultation and, hence, facilitating integrated resource decision making.

Introduction

Alberta Forestry, Lands and Wildlife is responsible for the administration and management of natural resources on public lands, including timber, wildlife, fisheries, watershed, forage, range, conservation and recreation. Good management of public lands requires a determination of the best and most appropriate use of the land considering its physical, economic and environmental constraints. In order for the Department to fulfil its mandate, the diverse users must have relatable and current resource information. The Department is developing a long-term approach for vegetation inventories in Alberta.

Background

The Department, in the past has undertaken many inventories to obtain the information to manage resources: land capability studies, timber surveys, wildlife population surveys, range assessments and biophysical studies for ecological reserves and natural areas. Such surveys have tended to be independent, single purpose resource inventories, with the major effort directed towards forest inventories since the early Fifties when the Phase 1 provincial inventory was conducted. A more intensive inventory on selected high priority areas followed in the mid-Sixties. In the Seventies, Phase 3 of the forest inventory, covering the completed Green Area, was initiated. Its completion was scheduled to coincide with the need to carry out an annual allowable cut calculation and provide a new allocation of timber to the forest industry by 1984 (Alberta Forestry, Lands and Wildlife, 1985). This inventory is today's data base for timber management planning and is used for detailed operational surveys.

The lack of a comprehensive updating program means that the forest inventory information is fast going out of date and, before responses to some questions can be given, lengthy update exercises have to be carried out. Today's different information requirements could not be envisioned when the inventory was started and changing resource utilizations have placed new demands on inventory. In the Eighties, three Alberta manufacturing plants introduced a new product-oriented strandboard utilizing aspen as the fibre. This tree was previously considered a weed species and the current forest inventory does not separate the aspen timber stands from the other hardwood species.

Today's decisions are made in a different manner and place unique requirements on the inventory system. Resource data should be integratable to facilitate inter-agency communication and consultation. One resource manager can no longer independently make decisions on resource allocation without considering the impacts on another resource. Increasing public concern about the environment and resource development proposals have increased demands for reliable, up-to-date information on all aspects of the resource.

Developing a Departmental Inventory

In 1985, following a Department (Alberta Forestry, Lands and Wildlife, 1987) study of GIS users needs, a decision was taken to develop an 'integrated' inventory system for vegetative resources. It was felt that a common inventory approach for timber, wildlife habitat, and range was not only feasible but would be cost effective. A four member Vegetation Technical Committee with representation from Fish and Wildlife, Alberta Forest Service and Public Lands was created. The first stage of the committee's work was the defining of a vegetation cover type classification for mapping purposes. This entailed identifying decisions made by each agency involving vegetation, describing the type of information product required to support the decision, and listing the data types that were required to build an information product. The result of this work indicated that a common stratification scheme for describing and mapping vegetation types was technically feasible.

The next phase of the committee's work was directed toward the development of field sampling methodologies. Range surveying was addressed first, as only two agencies were involved - the Grazing Section of Public Lands and Range Management of the Alberta Forest Service. A review of these two separate survey systems was undertaken, new data types were adopted, measurement criteria defined and standards established. A pilot project was undertaken in 1987 to test the new methodology and to incorporate necessary changes and this work culminated in the adoption of a common approach for range surveys for Public Lands and the Alberta Forest Service.

Also in 1987, the Alberta Forest Service was prepared to initiate a timber inventory for parts of the White Area (settled portion of the Province). Funding was allocated solely for a timber inventory, but, while work commenced on this, the Vegetation Technical Committee undertook a parallel project to examine operational cost data for the common vegetation classification developed in 1985. This cost feasibility study concluded that a single, integrated vegetation inventory system, to meet the vegetation needs of all Departmental agencies, could be undertaken with an incremental cost of ten percent to the proposed timber inventory. In 1988 a decision was made to adapt the timber inventory to collect a comprehensive set of baseline data for timber, wildlife and range resources. The new inventory is termed the *Alberta Vegetation Inventory* (AVI) and it represents the Department's first significant step toward the development of an automated relational resource data base (operational geographical information system).

Alberta Vegetation Inventory

The Alberta Vegetation Inventory is currently funded to cover an area of 500 townships (47 000 sq. km.). Aerial photography at a scale of 1:20 000 is used to delineate and describe vegetation types. Forest types are described for species, height, density, age and productivity class. Non forest types are described as shrubs, grasses, mosses or aquatic. Anthropogenic types include agriculture land which is described as either annual or forage crops. Digital covertype maps at 1:20 000 scale are produced using Intergraph and ARC/INFO technologies. The Intergraph system is used in the digitizing or data capture phase and the ARC/INFO capabilities are used in polygon processing and data file management. A volume sampling program is also under way and involves field sampling using fixed area plots. The objective of the volume sampling program is to achieve an accuracy of 20 percent at 95 percent confidence for the major timber strata.

Since the Alberta Vegetation Inventory is a digital database for baseline vegetation data it is intended that specific information products will be generated for individual users. On a pilot basis, a moose habitat evaluated map product has been generated by Fish and Wildlife Division using GIS software. Public Lands have demonstrated the capability of the data for displaying potential peatlands deposits.

There are some basic limitations to the current Alberta Vegetation Inventory, however. The existing commitment is to produce cover type maps for only 500 priority townships. Before going to a province wide production, there has to be exhaustive field test to evaluate the current products. As soon as budgetary resources permit, a system feasibility study will commence. This will address the design and implementation of the GIS database. Another important issue is the task of regular updating of the existing database.

Industry-Government Cooperation

At the same time that Alberta Forestry, Lands and Wildlife were addressing common information needs, data sharing and the development of automated information systems, similar events were happening in the private sector. The Alberta forest industry, keeping pace with the forestry sector in Canada, were evaluating the role of GIS. It was recognized the full benefits of GIS could only be achieved when the opportunities for data sharing were realized. Access to the provincial 1:20 000 digital basemap is of prime importance, as well as other information sets including forest inventory, land ownership and soil data. Joint developments of forestry GIS applications offer benefits. These concerns were the basis for a study prepared for the Alberta Forest Management Agreement (FMA) Holders and funded by the Canada-Alberta Forest Resource Development Agreement. This study was completed in December 1988 and indicated there was support for the development of an industry-government collective strategy for the implementation of GIS. One of the key recommendations was that "a common, shared forest resource data set be developed".

During the past five months, a "Vegetation Inventory Task Force", with representatives from industry and government has been meeting to identify the content of such an inventory, to define standards and to examine the feasibility of a shared data base. Again, the first step was to clearly define the information needs of the users. The Alberta Vegetation Inventory methodology and specifications served as the starting point for the deliberations. The Task Force work resulted in the establishment of the minimum standards for a provincial vegetation inventory and the conclusion that a shared data base for the depository of the data is feasible. Without the initial Department work that task would be almost unattainable within the time frame required. The next step in this exercise will require senior officials in industry and government to consider the recommendations of the Vegetation Inventory Task Force. They will have to evaluate the benefits of a common information system to the process of management plans submission and approval. Each year FMA holders provide annual operating plans for approval and the exchange of common information will facilitate this process. If there is cooperation on a data base design, additional savings may occur.

There are many other factors which will determine the ultimate outcome of these negotiations for a collective strategy for forest inventory. Existing FMA holders have considerable investment in their current inventories systems and the decision to change is of some magnitude. However, the Alberta Vegetation Inventory concept has been widely discussed and offers flexibility to the users. The recent expansion in the forest industry resulted in the establishment of new firms who, no doubt, will be the first participants in the provincial vegetation inventory system.

LRIS Network - AVI Relationship

The Alberta Government has been actively developing automated land information systems for the past fifteen years. The responsibility for leading and coordinating the orderly introduction of these systems has been assigned to the Land Related Information Systems Branch within Alberta Forestry, Lands and Wildlife (Alberta Forestry, Lands and Wildlife 1988). Figure 1 identifies the framework and the concept for the building of the provincial land related information systems. Three systems: the *primary*, *network* and *thematic* make up the overall plan. Most of the

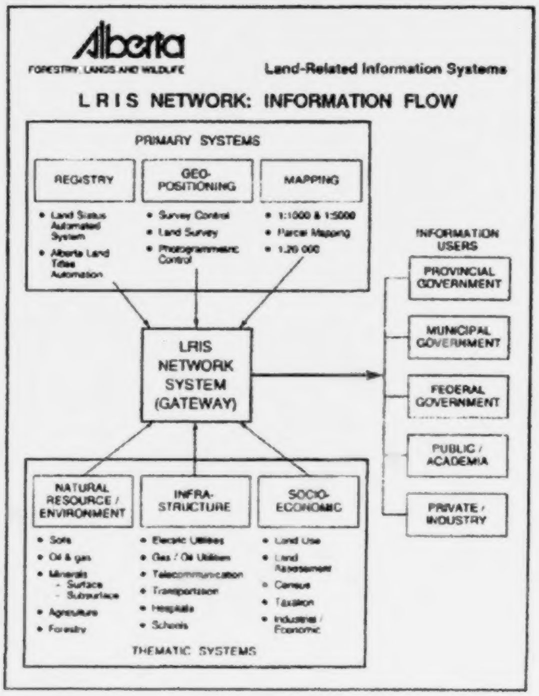
Alberta
FORESTRY, LANDS AND WILDLIFE
Land-Related Information Systems
L R I S NETWORK: INFORMATION FLOW
PRIMARY SYSTEMS
REGISTRY
GEO-POSITIONING
MAPPING
• Land Status Automated System
• Alberta Land Titles Automation
• Survey Control
• Land Survey
• Photogrammetric Control
• 1:1000 & 1:5000
• Parcel Mapping
• 1:20 000
LRIS NETWORK SYSTEM (GATEWAY)
INFORMATION USERS
PROVINCIAL GOVERNMENT
MUNICIPAL GOVERNMENT
FEDERAL GOVERNMENT
PUBLIC / ACADEMIA
PRIVATE / INDUSTRY
NATURAL RESOURCE / ENVIRONMENT
INFRA-STRUCTURE
SOCIO-ECONOMIC
• Soils
• Oil & gas
• Minerals
- Surface
- Subsurface
• Agriculture
• Forestry
• Electric Utilities
• Gas / Oil Utilities
• Telecommunication
• Transportation
• Hospitals
• Schools
• Land Use
• Land Assessment
• Census
• Taxation
• Industrial / Economic
THEMATIC SYSTEMS

Figure 1 - LRIS Network Concept

funding to date has been spent on the primary system to provide a digital 1:20 000 provincial base. Approximately sixty percent of the Province is now complete. Development work is now commencing on the network system which will permit computer access to the primary and thematic systems. In the future, the thematic system will be developed within this concept enabling users to enjoy the benefits of accessing and sharing a wide range of data, e.g., base maps. land ownership records.

Until recently, when forestry companies began investigating GIS, there was little involvement by the forestry sector in the Land Related Information Systems (LRIS). Companies viewed LRIS primarily as an opportunity to obtain up-to-date base maps for their forest inventory programs. However, the fundamental concept that has emerged from the government-industry discussions is that a joint forest management information system not only shares forest inventory information, but other data as well (survey control, topography, digital terrain models, hydrography, ownership). The LRIS concept provides the spatial framework and the structure on which to develop the proposed cooperative forest management information system.

The current Alberta Vegetation Inventory is of significance to the LRIS concept because it is the initial data set of the thematic system that is being developed. The concept of a shared resource database involving industry and government means that the data content, data specifications and the data exchange standards for this inventory will have to be established in conjunction with the LRIS Standards Management Subcommittee of the provincial LRIS Steering Committee. The specifications for the data elements of the vegetation inventory have been defined. There is now an opportunity for the LRIS Steering Committee to now actively coordinate the development of the thematic systems. This project has already spawned an LRIS Task Group to develop standards for hydrography and watershed data.

Ingredients for Success

Several factors have contributed to the progress made toward developing a provincial vegetation inventory.

Cooperation and Coordination

There has been considerable cooperation between users to establish the minimum requirements for information needs irrespective of agency or organization. There has to be a willingness to coordinate the data collection so that the required information is gathered in the most cost-efficient manner. The resource managers support a shared information system to improve the overall utility of the information.

Standardization

When several agencies participate in data collection and sharing of information, rigourous adherence to standards is required. Data elements must be defined and specifications for the measurements and coding of variables (e.g., species, tree height, tree diameter, single tree volume equations, UTM coordinates, watershed codes, administrative units, etc.) must be established.

Data Quality

Procedures and checks must be built into the system so that data from different sources can be aggregated and shared. Where different agencies contribute to the database the validity of the data must be assured. Photo interpretation based inventories present particular challenges. It will require good training and communication to ensure consistent interpretation from one interpreter to another. An explicit method for evaluating photo interpretation has been developed and the current AVI product has been used to establish a benchmark for evaluating the quality of photo interpretation. Similar efforts will have to be directed to insure sampling objectivity and the provision of unbiased statistical data.

Responsibility for Data Management

With this multi-agency shared resource inventory, the historical concept of 'ownership of the inventory' has shifted. The cooperation demonstrated in this project has been possible because no one user is in charge with others considered as 'add-ons'. Each participant must be and feel to be an equal partner with an equal voice. Instead of "Who owns the inventory?" there must be emphasis on the clear assignment of responsibility for 'corporate data management', that is, what is to be done, when it is to be done, and who is going to do it.

Conclusions

In the Eighties several events influenced the Alberta approach for handling natural resource information. The concept of integrated resource management has particular significance for data collection and data sharing and encourages shared, multi-resource inventory such as the Alberta Vegetation Inventory. The forest industry has been considering the introduction of GIS technologies. Maximum cost efficiency can only be achieved when such systems are compatible with provincial information systems to permit the sharing of information. The increased development of the forest sector recently, has given rise to several new forest companies in Alberta. These new firms are about to embark upon new forest inventories thus providing an impetus to develop a collective provincial strategy for forest resource inventories. Although significant progress has been made in the development of an approach for cooperative vegetation inventory, there are many challenges ahead.

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Development of an International GIS at Boise Cascade

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Abstract

Boise Cascade Corporation, since 1980, has worked with Geographic Information Systems for the development and maintenance of ownership and forest resource databases. Beginning with COMARC Design Systems and converting to ESRI's ARC/INFO in 1986, they have implemented a consistent approach to GIS in all regions from Oregon to Maine and Canada.

Some of the difficulties facing Boise Cascade over the years include:
- maintaining COMARC and ARC/INFO databases simultaneously,
- trying to maintain a consistent database corporate-wide while working with somewhat independent regional offices,
- managing basemap updates while continuing basemap development and implementing advanced GIS capabilities internationally, and
- developing tools that fit the needs of users with very different needs and problems

We will examine these problems historically and the progression of GIS at Boise Cascade. The current projects for streamlining basemap updates and development of a simple map products system will be highlighted. Future developments and plans for GIS at Boise Cascade will also be discussed.

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[1] *(formerly of Boise Cascade Corporation)*

Introduction

Boise Cascade Corporation (referred to throughout the paper as Boise Cascade) is amongst the largest timber companies in the United States, with holdings exceeding 6 million acres. With corporate headquarters in Boise, Idaho and regional offices from Washington to Louisiana to Maine and Canada, Boise Cascade is involved in a variety of timber industries including timber and wood products, office products, cardboard containers, plywood manufacturing and pulp and paper processing. They rely on a constant supply of timber and place great importance on managing information about the location, type, size and yield of that timber and more. Geographic Information Systems (GIS) have proven essential in managing these timber resources at Boise Cascade.

This paper will review the history of GIS at Boise Cascade over the past 10 years. This case study proves interesting because of the unique set of problems that have faced Boise Cascade. We will also look at the current efforts and future plans for GIS throughout the company.

Goals and Evaluation of GIS

Boise Cascade's plans to implement a GIS began in the late 70's and early 80's, when GIS was in its early stages of development as an industry. Boise Cascade's primary goal was to create a GIS database for tracking forest stand inventory. The anticipated primary benefit would be to allow the field foresters to make intelligent economic forest management decisions using the GIS on a day-to-day basis. The GIS would also allow computerized land ownership database for tracking sales and acquisitions of timberlands, basic stand basemaps, visual representation of 5 and 10 year harvest schedules, road maintenance programs, creation of region maps with up-to-date digital data and accurate net forested acre information.

In the early 80's, there were few GIS packages available. Boise Cascade reviewed several GIS prototypes before selecting a package by COMARC Designs Inc. COMARC had a fully developed digitizing package (CIMES) and was in the process of developing an interfacing tabular database module called FOREST. COMARC's only supported hardware platform was Data General.

Shortly after purchasing COMARC, Boise Cascade decided to write their own tabular database program, MIS, to store their stand inventory information as COMARC's FOREST module did not meet their needs. Boise Cascade also wrote a program, GEORGE, to query the MIS and display the results in tabular reports and maps.

The COMARC system allowed for 5 data labels for storing attributes about each feature. These labels were used to store key labels to uniquely identify each stand. The key information was also entered into the MIS tabular database, creating a method for linking the geographic features with the tabular information by way of the GEORGE program.

Development of a Geographic Database

Boise Cascade's GIS goals were to create a corporate-wide forest inventory database, with initial development beginning at the corporate headquarters in Boise. Over time, they planned on moving the maintenance into the regional offices where foresters would have immediate access to the database for use as a timber management tool. Data General minicomputers and COMARC software licenses were purchased for 8 regional offices as well as the corporate headquarters.

In 1981, Boise Cascade started hiring foresters and developing the GIS database at the Corporate headquarters in Boise. The goal was to develop a consistent corporate-wide database as well as train field foresters in the use of the GIS. The initial creation of digital data was done by digitizing of current basemaps, as very little digital data was available for purchasing in the early 80's. Finding accurate basemaps to work from proved to be a challenge, and often less accurate maps had to be used until better data was available.

The development of a large database produced unforeseen maintenance issues as each region's database came on line. By 1985, Boise Cascade had 7 out of their 12 regional databases digitized. Updating 7 large databases created two difficulties: scheduling basemap updates for all the regions to coincide with the regional field and office schedules, and maintenance soon became a full time job for the corporate headquarters GIS staff. Finding time to develop the remaining regional databases became a problem.

An internal GIS committee was formed with members from all the regional offices and the corporate headquarters to resolve the scheduling issues and give direction for future development of Boise Cascade's GIS. Contract digitizing, hiring of temporary 6 month digitizing staff and purchasing of available digital data helped complete the remaining regional databases.

Evaluation of ARC/INFO

In 1986, Boise Cascade decided to evaluate ARC/INFO as a replacement for COMARC. ARC/INFO was rapidly becoming a dominant force in the GIS market, especially in timber management, and the limitations of the COMARC software were hindering Boise Cascade's GIS development. The evaluation also coincided with a decision to work with DEC's line of VAX minicomputers in the corporate GIS office, and to use hardware incompatible with COMARC.

COMARC's inherent weaknesses and limitations were proving frustrating for the development of GIS at Boise Cascade. The lack of a full featured database integrated within the software, weak analysis programs, difficult conversions to the digitizing program data formats and limited cartographic output capabilities were driving the need to find a replacement for the existing GIS.

Boise Cascade undertook a benchmark study to evaluate ARC/INFO's abilities and determine the costs/benefits of switching to a new GIS. The benchmark study showed that switching to ARC/INFO would benefit Boise Cascade's future GIS goals. Some of these benefits included increasing database maintenance and basemap digitizing productivity, providing the field forestry personnel more user friendly query and display abilities, enhanced geographic analysis, better reporting capabilities, cartographic quality output and reducing the time spent on maintaining in-house written software programs.

Transition from Comarc to ARC/INFO

Even though ARC/INFO had features that made it a better solution for forest inventory and analysis, switching form COMARC to ARC/INFO would be expensive and time consuming. Since many of the Boise Cascade regions throughout the country had implemented COMARC prior to this time, a corporate wide decision to move from COMARC to ARC/INFO had to include interim solutions that would work throughout the company.

In conjunction with the conversion to ARC/INFO, Boise Cascade began implementing a corporate wide Total Quality Assurance program. This program involved looking at all the processes in maintaining a large international GIS including basemap digitizing, editing, conversions, schedule and delivery processes as well as database library management. Data quality was evaluated throughout the regional and corporate framework from data capture in the field by the field foresters to the return of the data to the foresters in digital format. ARC/INFO was also seen as a better solution than COMARC for implementing the Total Quality Assurance program.

Once the decision was made to switch form COMARC to ARC/INFO, several problems had to be worked out:

- Converting ARC/INFO data to COMARC for all regional offices still using COMARC,
- Retraining all personnel not only for ARC/INFO, but for DEC's VMS as well,
- Maintaining a link from ARC/INFO to COMARC to GEORGE and MIS, and
- Developing a plan for phasing out COMARC and implementing ARC/INFO corporate wide, as well as bringing other regions currently not using GIS on-line.

Boise Cascade worked with ESRI to first develop an interface between COMARC and ARC/INFO. This conversion had to go in both directions, from COMARC to get the existing data in ARC/INFO for editing, and to COMARC for use by the regional offices. COMARC's 5 data labels for storing codes linked COMARC to MIS and GEORGE were maintained in ARC/INFO exactly as they were in COMARC. MIS and GEORGE were seen as integral to the current GIS solution for Boise Cascade and the decision was made not to find replacements in the short term. The data conversion to and from COMARC translated these label positions as well, thus maintaining the link to GEORGE and MIS

The corporate phase-out of COMARC was a lengthy process. It took 4 years for Boise Cascade regional offices to complete the transition from COMARC to ARC/INFO. The cost for conversion to ARC/INFO had to be budgeted by each of the existing regional offices, as well as the cost for retraining staff. As a method for reducing costs of regional office conversion, the existing COMARC users decided to move ARC/INFO on their existing Data General platform, rather than switching to DEC equipment . Although this plan reduced costs for the regional offices, it added complexities to Boise Cascade corporate operations. The data conversion overhead could not be completely removed. A conversion of data from DEC VMS to Data General AOS operating system continues to be required. ARC/INFO includes utilities for converting map data between similar machines, making the operation simpler than with COMARC. As Boise Cascade moves into the next decade, multiple hardware platforms will continue to be a conversion problem.

Current and Future Uses of ARC/INFO

The primary use of ARC/INFO will continue to be basemap editing and updating. As regions become more expert in the use of ARC/INFO, the responsibility for map update will be shifted from corporate headquarters to the regional offices as originally planned for in the early goals. This shift will free resources at the Boise Cascade corporate office to work on integrating the use of GIS in more operations throughout the company.

With the help of ESRI, Boise Cascade has been developing applications for making ARC/INFO easier to use. Two sets of programs using the Arc Macro Language (AML) with pulldown menus and an intuitive user interface have already been developed: a basemap edit module, for speeding map updates and better ensuring data integrity, complete with map library features, and a query/map products module, to allow foresters to produce maps and reports based on MIS data easily.

Both of these application programs help implement some long term GIS goals at Boise Cascade. The basemap edit module uses some of the guidelines of the Total Quality Assurance Program. Staff editing maps are required to go through a series of steps after the data is edited. These steps, along with procedures for checking in and out maps from a library, help maintain data integrity. The query/map products module is a major step toward getting the GIS directly in the hands of the foresters in their day-to-day activities. Users do not have to know any ARC/INFO syntax or operations, allowing them to focus on the essence of the data rather than the technical details of the software.

In the future, Boise Cascade will continue their development of an integrated, international database throughout the company. Plans are being made for development of more sophisticated modeling and database analysis programs within ARC/INFO for use throughout the corporation. The initial goals of GIS development at Boise Cascade remain strong, and will guide their operations into the 1990s.

Hardware and Software Issues

Session D8
Microcomputers in GIS

Evaluation of PC-based GISs

Use of Autocad for GIS Purposes - Three Case Studies

PC-based GIS Helps Meet Government Reporting Requirements

PC System Configurations and Operations for GIS and Image Analysis

A Survey of GIS Use for Forestry Applications in Canada (Poster)

GIS'90 Symposium

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March 1990

Evaluation of PC-Based Geographic Information Systems

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Abstract
Expansion of PC-based GIS technology has created a lag in understanding of the available programs by many potential users. The complexity and diversity of available GIS programs makes it difficult to compare these programs. Many potential users rely on the vendor to provide benchmark figures regarding program performance. A preferred approach would be the development of independent benchmark standards and measurement techniques that could be used to compare systems in an unbiased manner. This paper describes efforts currently underway at the University of British Columbia Faculty of Forestry to develop independent assessment standards for GIS programs relative to forestry applications.

Introduction

Geographic information systems (GIS) are used for a variety of forestry applications including forest stand management, natural resource allocation, mapping, and forest inventory management (Consoletti, 1986). These spatial analysis programs are useful in assisting forest management at all levels, although few area managers, who actually coordinate and perform management activities, have access to GIS facilities.

Historically, GIS facilities have been operated and managed by mid-and upper-level management, allowing only limited access to GIS facilities by area-level forest managers (Smith and Prisley, 1989). Many geographic information systems incorporate expensive mainframe or minicomputers with sophisticated GIS programs to develop large spatially based management systems. These large scale systems often require a technical staff and financial support that are available only to upper management.

However, recent developments in microcomputer technology and advances in programming techniques have prompted the development of several advanced GIS programs based on the PC-DOS operating system. Capable of operating in a microcomputer-based environment, these programs offer many advantages over traditional GIS programs that work only on mainframe or minicomputers.

These 'low-end' GIS programs allow for reduced software and hardware investment costs, while providing spatial analysis features common to larger, more expensive GIS programs. A number of available programs, such as PCARC/INFO and PAMAP, are complete geographic information systems that have evolved from mainframe or minicomputer programs. Others, such as TERRASOFT, have evolved completely on the microcomputer platform.

The introduction of microcomputer-based GIS programs has made GIS technology available for forestry related analysis at the 'area' level. Potential users are now able to select from a variety of microcomputer supported programs for their application needs at fairly reasonable costs, as shown in Table 1. In addition, the hardware required to support PC-based GIS technology is now attainable for less than $20,000 Cdn. The improved analysis capabilities and the low cost of these systems will encourage many moderate to smaller sized forest products companies to take the 'plunge' into spatial analysis and GIS.

Current sales figures for ARC/INFO products suggest that this trend is already shaping the industry. PC-based versions of ARC/INFO currently outsell workstation versions by more than three to one, at a rate of ten PC versions per day, and outsell minicomputer-based programs by nearly twenty to one (Hemenway, 1990).

PC-based GIS programs currently being marketed to the forest industry include TerraSoft, PCARC/INFO, PAMAP, IDRISI, and SPANS. Each system takes a slightly different approach to geographic information analysis and the buyer is essentially expected to understand these differences before purchasing a system. Not only must the buyer have a grasp of the basic concepts associated with GIS technology, but this knowledge must extend to an understanding of how these techniques affect end use.

In many cases, the potential user has little understanding of how to evaluate different GIS features relative to end use. It is almost physically impossible to evaluate all the available programs prior to purchase. Finally, little comparative data is available from unbiased sources and independent benchmark tests are not generally available to evaluate the different features of GIS programs. In many cases, the user must rely on vendor supplied descriptions and benchmark test results to make the purchasing decision.

Instead of relying on sales pitches or abstract reviews of system performance, potential users of GIS technology should have access to an independent source to analyze and compare existing and emerging GIS products to determine the comparative abilities of these systems using independently defined standards and performance measures.

This paper outlines current efforts by the authors to develop meaningful criteria and benchmarks that can be used to critically compare existing and future PC-based Geographic Information System programs. Developed criteria and benchmarks can be used to analyze the capacity and performance capabilities of existing GIS programs for comparison purposes and to evaluate updated and newly introduced programs.

Assessment Methods

The purpose of this project is to construct a set of performance measures and benchmarking techniques for analyzing PC-DOS based geographic information systems and use the criteria to evaluate existing commercial systems such as TERRASOFT, PAMAP, and SPANS. The criteria and benchmarks developed from this work should help potential users in the forestry sector identify and select appropriate GIS technology for specific applications. Users can also make comparative evaluations of system features, develop cost-benefit analyses for different systems based on hardware and software costs and characteristics, and determine the application potential of a particular GIS package relative to other available programs.

The assessment procedure will be constructed so that individual GIS packages can be evaluated separately and compared against referenced sets of performance data, or benchmarks, to scale assessed performance. The proposed assessment criteria will focus on two topics, descriptive features and performance characteristics, as shown in Table 2.

Descriptive Characteristics: Basic information regarding the product and the vendor company will be included with descriptive information detailing features such as software structure, spatial analysis approach, system configuration requirements, and quality of documentation. A sampler of documented end uses will be provided to illustrate the type of projects and the level of sophistication that can be expected from the assessed program.

Table 1: Commercially Available PC-based GIS Software[1]

	HARDWARE REQUIREMENTS			
NAME/VENDOR/COST[2]	RAM	HARD DISK	MATH CHIP	COLOUR[3]
PCARC/INFO ESRI Redlands, CA Cost: $15-20,000 Vector Format	640K	Required	Required	All
TERRASOFT Digital Resource Systems, Ltd. Nanaimo, B.C. Cost: $15-20,000 Vector/Raster	640K	Required	Required	CGA/EGA
PAMAP PAMAP Graphics Victoria, B.C. Cost: $25,000	640K	Required	Required	EGA/VGA
IDRISI Clarke University Worcester, MA Cost: $100	256K	Suggested	Suggested	ALL
SPANS Tydac Technologies Ottawa, Ont. Cost: $20,000	640K	Required	Required	EGA/VGA
pMAP Materials School of Forestry and Environmental Science New Haven, CN Cost: $985	256K	No	Suggested	CGA
COMPUGRID/STRINGS Edmonton, Alb. Cost: $10,000	640K	Required	Required	EGA/VGA

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[1] Adapted from Buit, 1988.
[2] All costs in 1988 dollars.
[3] Refers to CGA, EGA, or VGA colour adapter.

Performance Characteristics: The performance assessment will focus on installation and operational aspects of the assessed GIS program using independently developed benchmark values to define performance. A base case will be used in the assessment which assumes that the user has no experience with GIS programs, but is moderately experienced with DOS-based microcomputers and the DOS environment.

Installation assessment factors will include an evaluation of the installation process, the level of integration between the software and the hardware, and configuration requirements. In addition, the assessment will consider the accuracy of written instructions provided in the installation and user's guides.

Developing Benchmarks: Installation and performance features will initially be developed for a program that has become the de facto standard for GIS technology. For this study, PCARC/INFO was selected for use in developing benchmarks because of the dominance of this program in the GIS marketplace (Lang, 1988).

Table 2: Proposed GIS assessment criteria[1].

DESCRIPTIVE CHARACTERISTICS:

1. Product Description
2. Company Name
3. Background - Sampler of end users and applications
4. Configuration of System
5. Software Package
6. Documentation
7. Limits of the System

PERFORMANCE ASSESSMENT CHARACTERISTICS:

Installation Requirements:

1. Program installation
2. Hardware/software integration
3. Software configuration
4. Integration with operating system and RAM resident programs
5. Other factors

Functional Performance (Benchmarks Required):

1. Data Input
   - a. From other programs (conversion utilities), ASCII files, etc.
   - b. "Institutional" formats such as TRIM and those supported by MoF and USFS.
   - c. From remotely sensed data - LandSat, SPOT, Meis, A.P.
   - d. From point source data
   - e. Using digitizer to input data

2. Data Editing
   - a. Cleaning up file - removing slivers, closing polygons,and deleting duplicate lines.
   - b. Updating maps and overlay

3. Data Analysis - effectiveness of the link between CAD and the database
   - a. Point and ask questions of objects on the map
   - b. Multiple queries
   - c. Overlay points/lines/polygons
   - d. Multiple overlay polygon
   - e. Interface to database
   - f. Perimeter and area measurements
   - g. DTM effectiveness

4. Data Output
   - a. To other programs
   - b. Printer/plotter output and peripheral installation requirements
   - c. Cartographic output

ARC/INFO has been commercially available for nine years (since 1981), with significant commercial success. The program evolved from a mainframe computer package that continues to set industry standards for GIS technology (Hemenway, 1990). Finally, the program is in wide use in the forestry sector and has evolved to a point where (presumably) few program operating errors exist.

Benchmark performance features are being developed using PCARC/INFO, Version 3.3. Benchmark criteria will focus on four topics; data input, editing, analysis, and output. A distribution of operational times will be developed to determine the mean time required to perform a particular task by a user working with a pre-defined data set. Similar tests will then be conducted with other PC-based GIS programs to develop data distributions for comparison purposes. The benchmark results from PCARC/INFO will provide a base set of comparison figures that should allow potential users a better understanding of individual program performance characteristics.

Results

Intermediate Results: Installation of PCARC/INFO in an IBM compatible PC was conducted to determine the length of time required to install the program and to identify any pertinent problems associated with the installation procedure outlined in the user's guide. Other factors considered during the assessment included integration of program components (i.e., spatial and database components), hardware/software integration, and integration between the program and the operating system. The forms used to collect the data on the installation are detailed in Appendix I.

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[1] Outlined criteria are abbreviated due to constraints on space.

The installation was attempted by a user familiar with the PC-DOS operating system, but unfamiliar with any aspect of PC-based GIS software. The program was installed on an AST 386-16 equipped with a 300 Mb hard drive, a printer, plotter, and four key digitizer.

Results indicate that PCARC/INFO has few installation related problems. However, significant differences were noted in the ease of installation for the ARC (spatial analysis) portion of the program relative to the INFO (data analysis) portion. The problems resulted primarily because of the poor quality installation guide provided with the INFO program.

Problems were also encountered when configuring and installing the four key digitizer. The four key digitizer was not directly supported by PCARC/INFO and technical support was required to complete the installation procedure. This problem might have been avoided by installing a digitizer supported by the ARC/INFO program.

This experience does indicate that problems can occur when introducing a GIS program to an existing computer system. Reconfiguration of equipment or even the purchase of special equipment may be necessary to obtain an operational system under these circumstances. Work is currently proceeding on the design of measurement techniques and the establishment of benchmarks for data input from a digitizer, standard format files, and remotely sensed data.

Expected Results: An outline of the benchmarks that will be developed during this study are provided in Table 2. As noted previously, benchmarks for data input are currently being developed using PCARC/INFO. To accomplish this, data input standards must be established, measurement techniques evaluated, and data must be collected.

Similar efforts will be made to develop benchmarks for data editing, analysis, and output. Substantial effort will be spent on the data analysis segment to establish benchmarks for analysis procedures pertinent to typical forest-based analyses. Vendor companies will be asked to assist in the development of these standard assessment procedures, since many of these companies currently conduct in-house benchmark tests and have valuable experience in the structure and development of these tests. After developing benchmark standards and measurement techniques with PCARC/INFO, other programs will be assessed to produce evaluations of many PC-based GIS packages currently available in North America.

Conclusions

As PC-based GIS technology continues to evolve, more programs will be introduced to meet the increasing demand for GIS software. The forest sector will continue to expand its use of GIS technology with particular emphasis on microcomputer-based programs.

Research is needed to address the complex problem of evaluating and selecting appropriate microcomputer-based GIS software that can resolve the analytical needs of the forest sector. Work should focus on development of assessment standards and benchmarks that are accessible, understandable, and useful. More importantly, these standards should be derived by a reputable independent agency capable of producing unbiased results.

The research outlined in this paper will eventually produce an unbiased set of standards and benchmarks that can be used by the forest sector to evaluate new or updated geographic information systems. In addition, this work can be used by other resource sectors to develop relevant benchmarks.

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Appendix I

Preliminary Installation Assessment Questionnaire

3.11 - Software Installation:

1) Were installation instructions easy to find in the manual?
2) Were keyboard input instructions clear and correct?
3) Was the installation process indexed?
4) How many attempts were made before the installation procedure was completed?
5) Was technical assistance required?
6) Total time to load program:

3.12: Hardware Installation:

1) Were installation instructions easy to find in the manual?
2) Were keyboard input instructions clear and correct?
3) Was the installation process indexed?
4) How many attempts were made before the installation procedure was completed?
5) Was technical assistance required?
6) Total time to install hardware:
7) How many devices are installable/supported by the user?
8) Can user define own device?

3.13 Program Integration:

1) Was the database supplied by the company supplying the GIS?
2) Was there continuity between the GIS installation and the database installation?

3.132 Hardware/Software Integration:

1) Were there any problems integrating the GIS with the monitor?
2) Were there any problems integrating the GIS with the digitizer?
3) Were there any problems integrating the GIS with the plotter?
4) Were there any problems integrating the GIS with the printer?

3.14 Integration with Operating System and RAM resident memory:

1) How much RAM Memory does the program require?
2) Can the GIS access extended/expanded memory?
3) Does the program allow for other RAM resident programs to be loaded while the GIS is running (ie; Sidekick Plus, PCTools)?
4) Can you go to DOS and leave the program in memory?

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Use of AutoCad for GIS Purposes - Three Case Studies

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Abstract
AutoCad was used for three GIS projects as either an entry-level GIS system or as an inexpensive method to supply digital data to more sophisticated GIS systems. The advantages and disadvantages of the methods and the software used are here examined.

Introduction

AutoCad is a powerful software tool available on microcomputers which permits the manipulation of primarily graphic elements, but can link non-graphic data to these elements through dBASE. The package's comparatively low cost, its ease of operation and its availability in several languages have placed AutoCad at the forefront of the low-end CAD market, which is increasingly dominated by microcomputers. Its linkage to dBASE gives AutoCad some GIS-like functionality.

Intera Kenting is undertaking three GIS-like projects using AutoCad software:

(1) planimetric base mapping for forestry inventory in the Central African Republic (CAR),

(2) a pilot project for the establishment of 1:12 500 forest inventory maps based on photointerpretation for the Province of Newfoundland, and

(3) the integration of radar imagery and geophysical data for the Ontario Ministry of Natural Resources.

These three projects will now be discussed in greater detail.

1. Central African Republic

1:50 000 scale planimetric base maps were required by the CAR in order to map forestry species in areas where indiscriminate felling of trees has led to severe impoverishment of the nation's hardwood forests. New air photographs at 1:50, 000 and 1:20 000 scales were taken to map the forest cover and update the planimetric base of existing

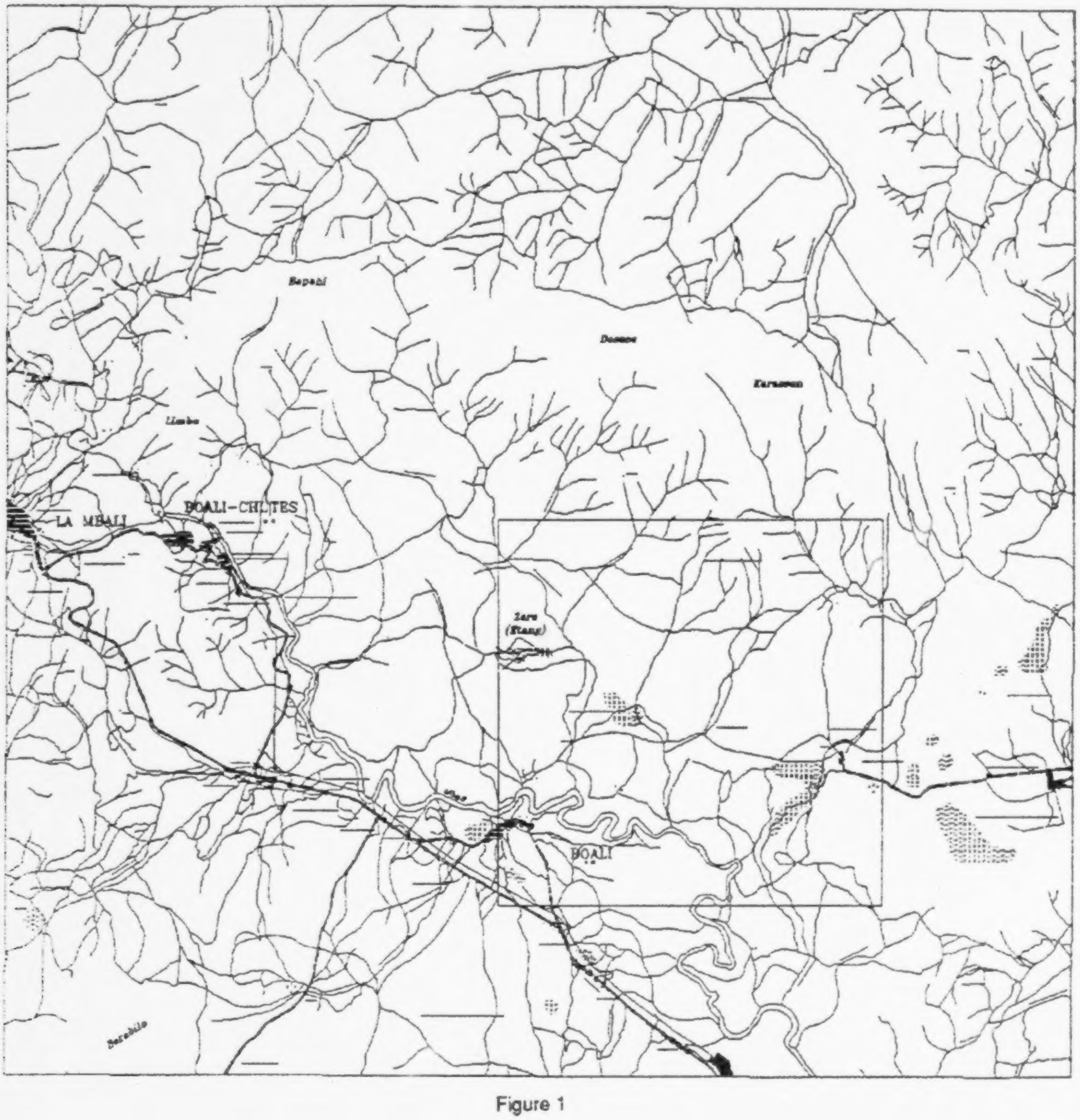


Figure 1

map sheets. These were either 1:200, 000 or comparatively older 1:50 000 scale topographic sheets.

The CAR adopted AutoCad because it was available for microcomputers in the French language. Other systems did not meet these requirements and had to be dismissed as options.

The first step consisted of digitizing the drainage and major roads from the existing maps using the UTM coordinate system. The new 1:20 000 airphotos were interpreted for planimetric features (roads, trails, buildings, etc.). During this second step, UTM coordinate values digitized from the base maps were transferred to the airphotos where the points were clearly identifiable.

The third phase consisted of updating the digital planimetric base using the interpreted airphotos. These were registered piecewise to the digital base using the above-mentioned points. This procedure does not fully eliminate relief distortion from the airphotos but the residual positional errors attributable to relief variations are usually smaller than the error inherent to the process of digitization. For the purposes of updating planimetry on existing sheets, this methodology is more cost-effective than digital stereoplotting of adjusted photo models, particularly when the photo scale is greater than the output map scale.

The digital base , an AutoCad .DWG file, containing spatial elements placed in various layers (drainage, footpaths, motorable roads, buildings, etc.) is seen in Figure 1. The fourth phase will be carried out by forest surveyors in the CAR. This will entail interpreting 1:20 000 and 1:50 000 airphotos for forest associations and classification. The polygon boundaries will be traced onto the photos and digitized into the map base using the piecewise registration method of phase 3.

Figure 2 shows some forestry polygons overlaid on the digital base for a 10 km x 10 km portion of a map. Figure 3 shows the position of the block relative to the entire sheet. Polygons may contain centroid pointers which are AutoCad 'blocks', related to a dBASE file which contains non-graphic attributes regarding the forest composition of the polygon.

This system will permit the authorities in the CAR to:
1. update both the graphic and non-graphic attributes of the forestry database via either dBASE or AutoCad,
2. create plots at various scales of all or selected portions of a particular map sheet.

2. Newfoundland Forestry
The Department of Lands and Forests of the Government of Newfoundland maintains an ARC/INFO database of the Province's forest cover. The files are organized to conform

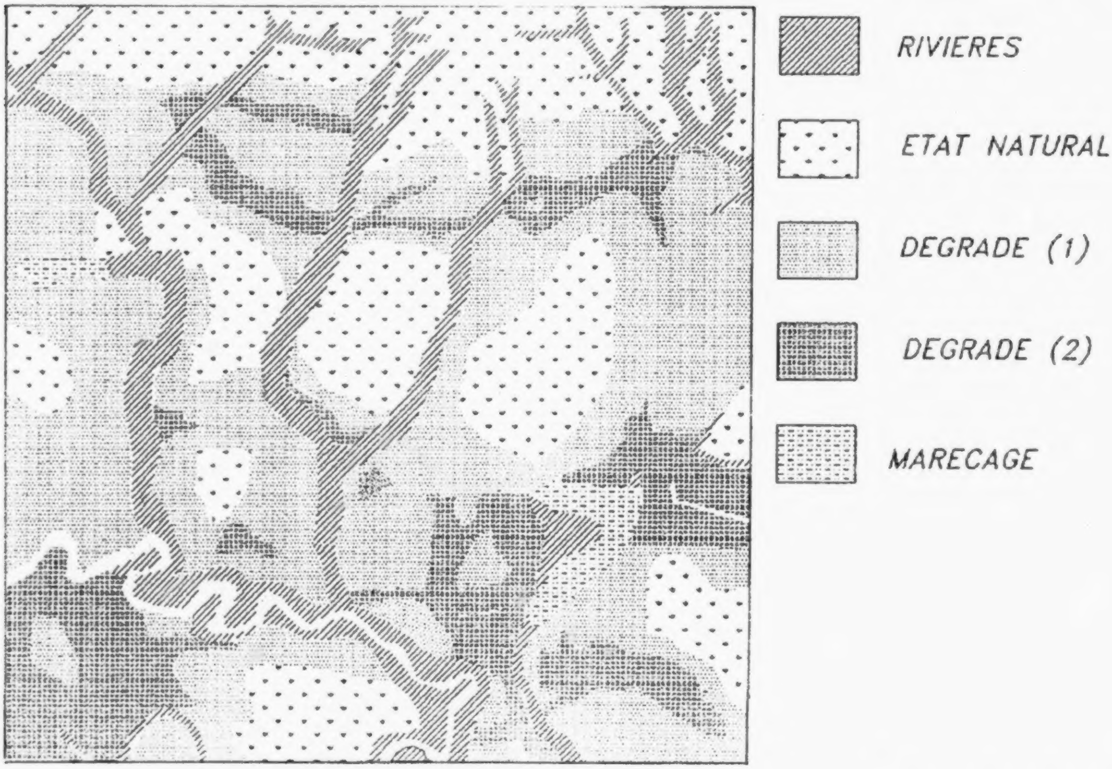


Figure 2

to 1:12 500 scale map sheets of which there are 16 per NTS 1:50 000 scale topographic sheet.

Forest cover is mapped using interpreted colour air photographs. Traditionally, polygon boundaries have been projected optically onto a map sheet and by pencil and then digitized. This is both cumbersome and error-prone as the optical projection system must be continually adjusted to compensate for distortions in the photographs, and positional errors can occur during tracing and subsequent digitizing.

As a 'test' project, Intera Kenting digitized the boundaries directly from the airphotos using AutoCad software. First, the base map was digitized for relevant planimetric data. This database supplied the control information for the air photographs for points that were clearly identifiable; these points were then used to correlate portions of the photographs to the digital base in a piecewise manner.

The polygon boundaries and other planimetric information were then trimmed to the map boundary, a proofplot was made and errors of omission were corrected by resetting the appropriate photographs. The AutoCad file, shown in Figure 4, was then converted to SIF and imported to the ARC/INFO system, which then 'cleaned' and 'built' the polygon topology and created the polygon attribute tables. Data were delivered to the client on magnetic tape using the ARC/INFO export format.

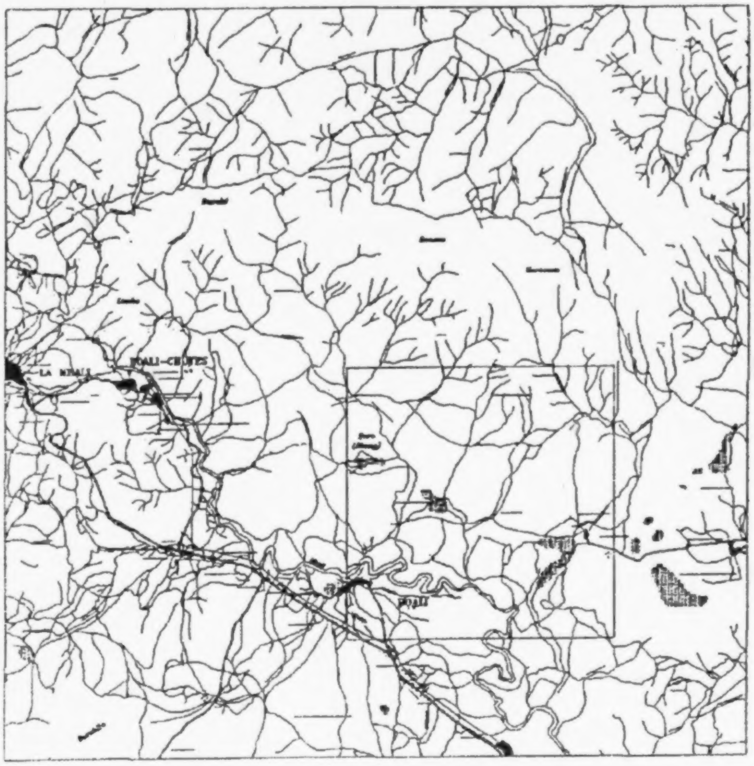
The advantages of this methodology are:
1. the elimination of the optical projection system,
2. the use of relatively inexpensive AutoCad software for digitizing.

3. Government of Ontario Data Synthesis

The Ontario Geological Survey has asked Intera Kenting to create an AutoCad database comprising airborne magnetic data, gravity data and radar imagery of 96 10 km x 10 km map sheets of a portion of Northern Ontario. The radar imagery provides "background" information in lieu of digitized drainage and other planimetric features as shown in Figure 5.

The radar data from a 1988 airborne SAR survey was in raster format with byte-coded intensities varying from 1 to 255 on a grey scale. The airmag and gravity data consisted of irregularly-spaced x,y, and z values.

The raster data were converted into vector format and run-length encoded to reduce file space. The grey scale was reduced to seven levels suitable for viewing on an AutoCad system equipped with a sync monitor yet capable of displaying 256 colours. AutoCad's DXB format was used for data transfer.



STATUS OF NATURAL FOREST COVER

Figure 3

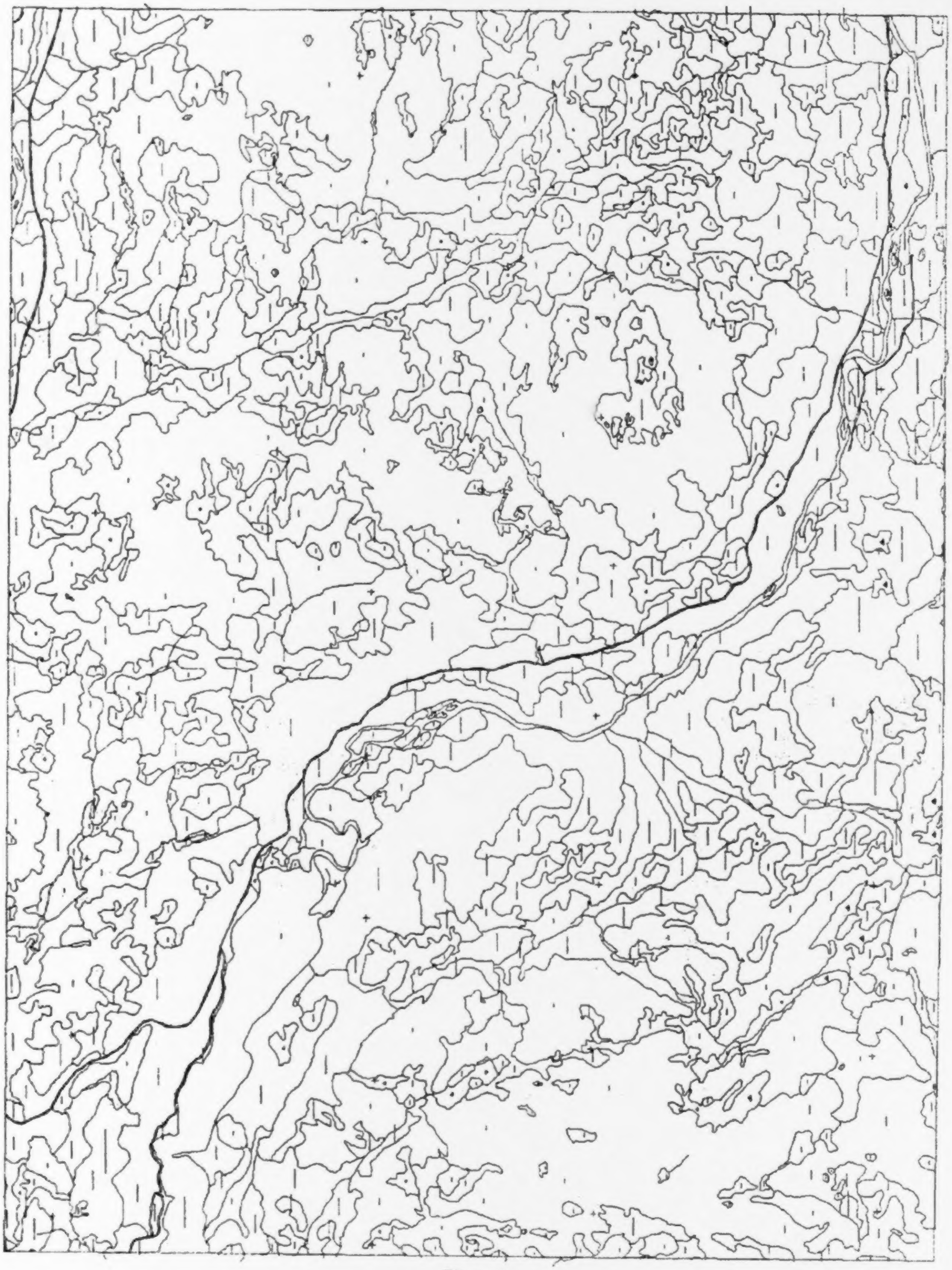


Figure 4

The gravity and airmag data were interpolated by inverse-square distance and a gridded database using regular spacing was produced for each map sheet. These grids were contoured using a surface-modeling package (SURFER) and plot files were converted to AutoCad DXF format as shown in Figure 6.

The AutoCad database was organized into several layers which can be turned on or off as required. Ministry personnel can load these data into PCs in field offices or into portables in the field. Additional data such as bedrock information, the occurrence of mineralization, etc., can be input into user-defined layers and merged with the existing database.

Non-graphic attributes such as the results of assays can be linked to the graphics via dBASE using a 'block' insert as a pointer to the location.

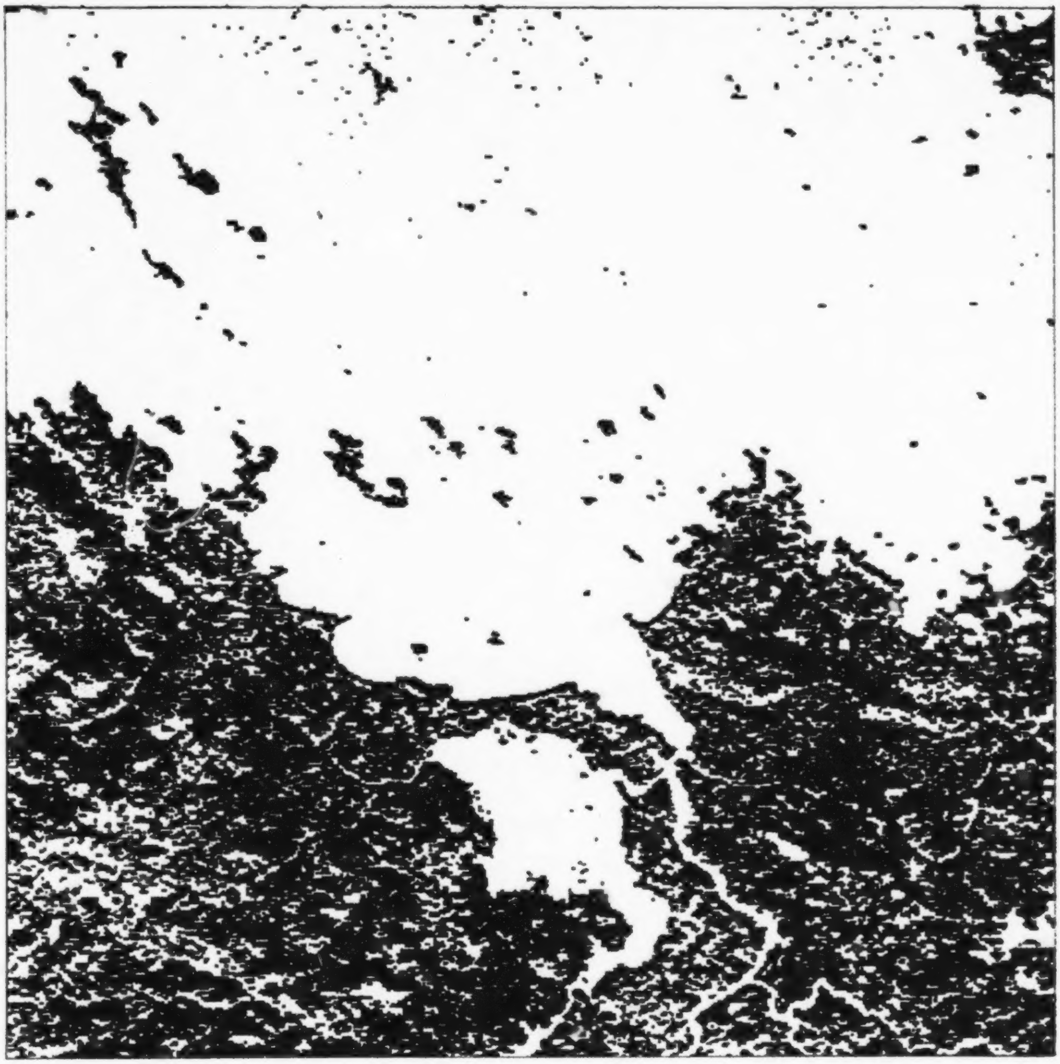


Figure 5

4. Conclusions

AutoCad can be used as an inexpensive, entry-level GIS system. The main advantages are:

1. Its comparatively low cost,
2. Its ability to function on any PC equipped with a numeric coprocessor,
3. Its ease of communications with other systems (IGES,DXF,DXB for graphics and CDF and SDF for non-graphic data),
4. Its artificial intelligence interface (AutoLisp),
5. Its linkage to dBASE,
6. Its unlimited layering.

The disadvantages of this system for GIS are:

1. Two software packages must be used concurrently. The operator must be familiar with both AutoCad and dBASE, and interactive work entails time-consuming hopping from one package to another.
2. Some custom software development is required to transfer data between systems, particularly when imagery raster data must be vectorized and converted to AutoCad format. Moreover, such data files become very large when in AutoCad format and this affects system performance.

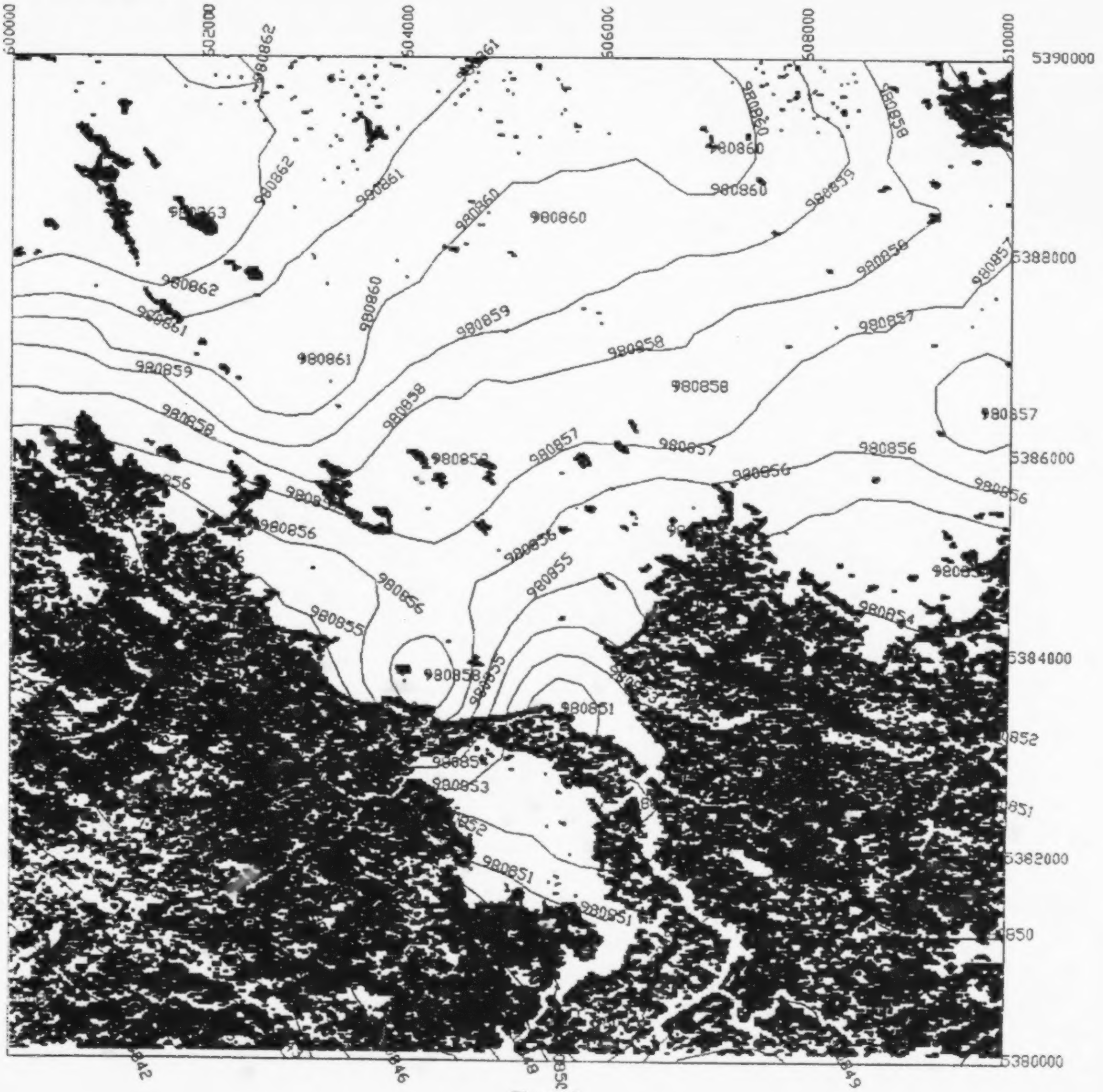


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Figure 6

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PC-based GIS Helps Meet Government Reporting Requirements

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Abstract

Recent court rulings on the tax associated with unmined coal reserves prompted the Kentucky Department of Revenue to require coal companies to compile their information. In addition, much of the information is difficult to represent on the USGS quadrangles required as base maps. As the need for coal owner's ability to produce justifiable and complete reserve maps increases, so does the need for conversion to automated mapping. To ease the management of such information the coal owner chose to implement a PC-based GIS system that works in conjunction with AutoCad.

Recent court rulings on the tax associated with unmined coal reserves prompted the Kentucky Department of Revenue (DOR) to require what some coal reserve owners and lease holders to believe is a cost-prohibitive compilation of information. Besides the cost involved, much of the information is difficult to represent on the USGS quadrangles required as basemaps.

The first and obvious problem with such a map is that few coal owners have this information available in a USGS format. Drilling information may exist at one scale while parcel and other boundaries exist at another. Merging this information onto one map can be difficult and time consuming. Furthermore, the scale of the required map itself causes undue problems.

For example, consider an area of around 1000 acres. To map such an acreage on a 1:24 000 quadsheet requires nearly eleven square inches of map. This map is 3.3 inches square if the area were roughly square. The basemap required by the DOR must show parcel boundaries as well as drilling information. Such an area could easily contain over 100 drill holes. The hole location and name alone would be such a conglomerate of symbols as to make the map unreadable. Even if the map could be made readable, a list of code numbers that relate to the map would have to be supplied to correlate the map to the drilling and parcel information.

While drilling and parcel information must be on the basemap, this is far from being all the mapping required by the DOR long form. Permitted, underground, surface, mined, leased, mineable and unmineable areas must also be mapped at the same scale. Since each of these areas is distinctly different, a separate quadsheet could be required for each.

While the required mapping is cluttered for any coal reserve, large or small, the truly difficult task is deciding how each parcel should be assessed. For example, questions such as "How much of parcel A is underground mined? How much of parcel B is unmineable?" become the items which drive the cost of supplying the required information to extremes.

Much of this problem is solved by realizing how this information is to be used. Obviously the DOR is not going to shuffle hundreds of pages of the same quadsheet to determine the value of an unmined coal reserve. The intentions are to convert the individual quadsheets into a conglomerate digital computer map of the Kentucky coalfields. Providing the information in a form that the DOR computer can read directly appears the simpler answer. The following example is such a solution one coal reserve owner used to negate the need for even a single map.

The owner has over 75 000 acres of reserves requiring filing on the DOR long form. The area consists of over 500 individual parcels. Drilling information spans over twenty years and resides on a variety of maps. Many portions of the area are permitted, leased, mined, underground and surface reserves. Much of the area contains producing oilfields or a high density of residences.

To ease the management of such information the owner chose an inexpensive computer program developed by Facility Mapping Systems, Inc. in Mill Valley, California. The program was originally developed to handle the large land based information system required by a mining operation. The graphical data is entered with Autocad, a computer-aided drafting package. Each map was in turn calibrated to the Kentucky State Plane coordinate system and entered into the single computer map. One operator on a single desktop computer entered coal areas, permitted areas, leases, parcel boundaries, croplines and depleted areas. Houses, roads and oilfields all have zones associated with their locations making these areas unmineable. Because of insufficient roof support underground reserves were deemed unmineable as were areas below crop or previously mined. Once converted to a digital computer file, the hard copies of these factors were no longer needed.

The true power of the computer files then enters into the preparation of the forms. The computer program merges each of these maps into a what would appear to be a puzzle. Each piece of the puzzle then becomes a unique area as shown in Figure 1. The computer creates a record for each piece that describes whether it is: underground or surface reserves, minable or unmineable, leased, in parcel A, etc.

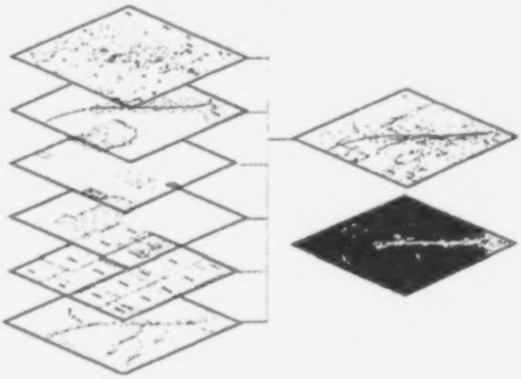

Figure 1

To satisfy the DOR, the computer enters each piece of the puzzle into a file that gives the state plane coordinates of its corners and a complete description of the piece. All the maps and drilling information were transferred to two floppy disks and sent to the DOR. There it is read by computer and entered into the statewide database without the need for a single map.

With the same time as required to create the maps by hand on a quadsheet a single person operating a desktop computer supplied the DOR the information for over 500 parcels and 75000 acres of reserves. However, this owner now has produced maps with a significant side benefit. All the maps now reside in a computer, where they can be manipulated, plotted as a map in any scale or modified with ease. Additional information such as production, mine plans, royalty information can easily be added to the map as the owner sees fit to compile.

While not every coal reserve is complicated enough to require this process, it does lend a credibility to conversion of hard copy maps into computer files. The large dedicated mainframe mapping computer of the past and the staff to operate it has been replaced. A single desktop computer and operator can now provide information faster, simpler and more accurately than ever. As the need for coal owner's ability to produce justifiable and complete reserve maps increases, so does the need for conversion to automated mapping.

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PC System Configurations and Operations for GIS and Image Analysis

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Abstract
There can be difficulties associated with the installation, operation, and maintenance of a GIS and/or image analysis system on an IBM/MS-DOS PC-based workstation. The increasing requirement for large data storage has conflicted with the high memory requirements of the GIS and image analysis software programs. The economic and practical necessities of operating complementary applications such as statistical packages, spreadsheets, data bases and word processing have also posed operating constraints. Optimal computer performance solutions to be implemented include device driver management, overcoming the DOS 640 Kb conventional memory limitation, managing shadow and extended memory, optimizing disk buffers and caching utilities, writing batch files, and using TSR programs. Though these solutions are software-based, an intimate understanding of the capabilities and limitations of the computer hardware platform is required. Increasing difficulties are being reported on available memory, with respect to the relation between increasingly larger logical hard disk partition size and the corresponding increase in memory required by DOS buffers. The suitability of the 80386 over the 80286 for production applications is reviewed, since it offers several advantages of larger memory addressing, faster clock speeds, multitasking, downward compatibility and a larger software base. Recommendations are given for hard disk management, file management assisted by utilities, minimizing file fragmentation, and the necessity for routine backups.

The mention of any trade names does not imply endorsement by the authors or their institutions nor does it constitute criticism of similar products not mentioned.

Introduction

The installation and operation of a GIS and/or image analysis system on a personal computer (PC) may result in difficulties associated with available memory and processing speed. Achieving an optimal configuration is becoming increasingly difficult, as these software packages increase in size while constrained within the Disk Operating System (DOS) limitation of 640 kilobytes (Kb) conventional memory. Several GIS systems are now requiring upwards of 580 Kb and in some cases, extended memory to function reliably. This results in only 60 Kb of conventional memory being available for the DOS, device drivers, disk buffers, and terminate and stay resident (TSR) programs.

Depending on partition size, large disk drives (i.e., 130 megabytes (Mb) and larger) will also influence the size and number of individual disk buffers needed and thus the amount of conventional memory required (TYDAC 1989).

Economic and practical necessity demands that a computer system be adequately flexible to support more than one computer application. Complementary applications such as statistical packages, spreadsheets, data base management systems and word processors, have specific memory and configuration requirements which may conflict with the GIS system.

Networking to communicate and exchange information with another computer system is also becoming increasingly important. Connection via direct line, ethernet, or modem with mainframes, minicomputers (e.g., Digital VAX) and other PCs each have unique requirements for device drivers, interface cards, and operating memory.

How can a multiple platform operation be achieved on a PC, given the limitations posed by the operating system? This paper will describe optimal computer performance solutions with respect to managing computer memory, device drivers, memory resident programs, and disk buffers and caching utilities. Complementary to achieving an optimal configuration, however, is maintaining its performance. Procedures and recommendations will be described on how to minimize file fragmentation, implement file management procedures, and perform regular backups.

Why a 386?

With the availability of inexpensive fast 20 megahertz (MHz) 80286 AT computers, the question may arise as to why select a 80386 over a 80286 computer for GIS and/or remote sensing applications? There are several technical factors and cost considerations that govern why an 80386, rather than an 80286, would be preferable for PC-based GIS installations.

The 80386 is a true 32-bit processor compared to the 16-bit processor of the 80286 (Petzold 1986), and is upwardly compatible with its ancestors, 8086, 8088, 80186, 80188 and 80286. This means that virtually all software written for these ancestor microprocessors will run on the 80386 (Petzold 1986), although the converse is not true. The 80386 design process, unlike the 80286, had input from major developers and had OS/2 and DOS in mind (Machrone 1989).

At power-up, the 80386 and 80286 microprocessors function in what Intel calls real mode (Petzold 1986, Duncan 1989). In real mode, the 80386 and the 80286 central processing units (CPUs) generate 20-bit memory addresses. The maximum amount of memory that can be addressed in real mode is therefore 2^{20} bytes or 1 Megabyte (Mb) (Petzold 1986). Real mode enables the 80386 and 80286 to retain their upward compatibility.

The 80386 and 80286 also function in what Intel calls protected mode (Petzold 1986, Duncan 1989). In protected mode, the 80386 and 80286 are no longer upwardly compatible with their ancestors. In protected mode, the 80386 processor has access to 2^{32} bytes or 4 gigabytes[1] (Gb) of addressable memory because the 80386 chip has 32 address lines. Similarly, the 80286 has 24 address lines and thus has access to 2^{24} bytes or 16 Mb of addressable memory. The 80386, consequently, has considerably more addressable memory[2] than the 80286. Protected mode can also access virtual memory. Virtual memory allows the use of data stored on a hard disk as though it were stored in memory. The 80386 can access 64 terabytes[3] (Tb) of virtual memory address space compared to the 1 gigabyte (Gb) of virtual memory addresses that the 80286 can access. To switch between real and protected modes is far simpler on the 80386 than on the 80286 (Machrone 1989).

One major advantage of the 80386 over the 80286 is the available memory management capability (Nimersheim 1989). The 80386 microprocessor supports virtual 8086 sessions, which means the 80386 can imitate a one megabyte addressing environment which appears to be an 8086 computer to existing programs (Petzold 1986). More significantly, several 8086 environments can be maintained concurrently and are only dependent on available memory (Nimersheim 1989).

The recent availability of the 16 Mhz and 20 Mhz 80386/SX-based computers have complicated the selection between them and 80386 or 80286-based computers. Internally the 80386/SX and the 80386 microprocessors are identical (Drude 1989). The 80386/SX is therefore software-compatible with the 80386 (Dickson 1989). There are however, a few differences between these two microprocessors. The 80386 microprocessor contains 32 data lines and 32 address lines. Similar to the 80286, the 80386/SX microprocessor contains 16 data lines and 24 address lines (Drude 1989). The maximum addressable memory the 80386/SX can access is 16 Mb. The 80386, because of its 32-bit data bus, is inherently faster than the 80386/SX and the 80286 (Drude 1989). The advantage of the 80386/SX over the 80386 is cost. The 80386/SX is cost comparable to the 80286 and is therefore less expensive than the 80386.

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[1] 1gigabyte = 10^9 bytes

[2] $2^{32}/2^{24} = 2^8 = 256$ times as much addressable memory

[3] 1terabyte = 10^{12} bytes

DOS operates only in real mode on 80386 and 80286 microprocessor-based computers since it was strictly designed for the 8086/8088 microprocessor. This explains why DOS is unable to employ technological advances such as 32-bit registers, maximum segment size of 4 Gb and support for up to 64 Tb of virtual memory (Davis and Rosch 1989). The inability of DOS to run in protected mode also results in a 80386 and 80286 with similar clock speeds to achieve roughly the same performance. There is, however, DOS-based software already written to take advantage of the features of the 80386 (i.e., Windows386, DESQview386, etc.) and more is continually being developed. These software packages provide access to more than 1 Mb of memory and multitasking capabilities to DOS (Rosch 1989).

Optimal Performance

Among the major components of achieving optimal performance from a PC-based GIS or image analysis system include managing device drivers, TSR programs, memory, buffers, disk caches and batch files. The purpose of this section is to describe what they are and how they can be managed and configured for GIS or image analysis operations.

Device Drivers

When DOS was developed, the designers published specifications so hardware manufacturers could develop their own software modules, called device drivers, that would access the operating system (Somerson 1988). Device drivers are program modules which provide a communications interface between DOS and various peripheral devices. In this way, DOS wouldn't need to be upgraded each time new hardware devices were developed.

DOS generally installs device drivers from the file CONFIG.SYS at power-up. Device drivers are loaded into conventional memory directly above the operating system's file-control blocks and disk buffers. Device drivers become permanently resident in memory and act as extensions of the operating system (Rizzo 1989). Conventional memory available for the GIS and/or image analysis system is therefore reduced by each device driver added. Not all device drivers are needed concurrently . For optimal performance device drivers that are not needed should be removed from the CONFIG.SYS file. If a tape drive is a peripheral and is only used for backups, for example, then the tape drive device driver should only be installed when backups are to be performed.

Guidelines for Managing Device Drivers

There are two methods of managing device drivers from the CONFIG.SYS file. The most common method is to have multiple CONFIG.SYS files with different names or extensions with unique combinations of device drivers for particular applications. The required configuration is then copied over the CONFIG.SYS file and, by re-booting, the new control file takes effect. This method is cumbersome, especially if there are many CONFIG.SYS files. A more efficient method is to use a boot interrupt like CONFIG.CTL[4] which facilitates the user selection of device drivers to be installed by CONFIG.SYS at boot-up. This kind of boot interrupt is especially useful for trouble-shooting and determining an optimal configuration when new peripherals or software programs have been installed. It also eliminates the requirement for multiple CONFIG.SYS files. The use of a boot interrupt is particularly beneficial in multiple platform operations and in PCs that support both GIS and image analysis systems.

TSR Programs

To appease demands for multitasking, the first developers of DOS 1.1 introduced a terminate-and-stay-resident function call. A few background printing utilities that utilized this function call were included with DOS 1.1. These utilities were useful but not interactive. The perceived benefits of the TSR function call resulted in availability of several RAM-resident utilities such as Sidekick. TSR utilities are typically installed into conventional memory after DOS during the execution of the AUTOEXEC.BAT file, and remain in memory while application programs are being executed (Raskin et al 1986). Interactive TSRs install keyboard interrupt handlers that look for special key combinations called a 'hot key'. When the appropriate key combination has been entered, the current process image is saved and control is passed to the TSR program. When the TSR is finished,the process image is restored and the original program continues from the point of interruption.

TSRs can be very useful but there are inherent problems associated with their use. DOS was not designed to be a multitasking system. RAM-resident programs therefore exist in an environment that was never meant to support them. If two RAM-resident programs use the same hot key sequence (the most common problem), collisions will occur when the two programs attempt to write into the same place in memory. Memory limitations can cause difficulty as well. If several TSRs have been installed, GIS and/or remote sensing programs which are memory intensive will have difficulty operating to their full capabilities.

Guidelines for Employing TSRs

For optimal computer performance, it is highly recommended to install as few TSRs as possible. TSRs that can be removed from memory without re-booting should be preferred to those that cannot. Most TSR programs cannot remove themselves from memory and the computer has to be re-booted to remove them. Use TSRs that have definable hot keys. Until multitasking in the DOS environment becomes an easily implemented reality, use only the TSRs that are essential for the specific program or application that requires them. One approach is to install TSRs by executing batch files rather than placing them all in the AUTOEXEC.BAT file.

Buffers And Disk Caching

A buffer is a portion of RAM, set aside by DOS, that contains data recently read from or written to a disk (Somerson

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[4] A special device driver that allows you to modify config.sys configuration dynamically. It is public domain software (Mefford 1989).

1988). The number of buffers specified can affect the speed at which an application program reads and writes from a disk. Each additional buffer, however, demands an additional 512 bytes of RAM. This reduces the amount of RAM available to the application. Every PC configuration has a unique optimal amount of buffers. Choosing more or less than the optimal number of buffers can degrade performance (Mendelson 1989).

There is a relation between the amount of RAM for each DOS buffer and the logical partition size on the hard disk. The larger the partition, the larger the amount of RAM for each buffer (TYDAC 1989). This has become an important concern with the increasing use of larger physical disk drives of 130-300+ Mb, in PC-based GIS and image analysis systems, unless the partition size is limited to the nominal DOS 3.3 limit of 32 Mb. Large disk partitions although convenient, are therefore not necessarily optimal from a computer performance perspective.

Buffers are a primitive attempt by DOS at disk caching. A disk cache can reduce hard disk access time by a factor of 10 and floppy disk access time by a factor of 50 (Mendelson 1989). Disk caches, like buffers, reduce access time by producing data from RAM rather than from a hard drive.

Managing Buffers for GIS and Image Analysis Systems

DOS 4.01 permits DOS buffers to operate in expanded memory. Memory managers such as QEMM will provide utilities such as BUFFERS.COM and LOADHI.COM that allow the moving of DOS buffers into available memory in the 384 Kb shadow RAM. Alternatively, the amount of buffers can be reduced to a very small number and a disk cache could be installed into extended or expanded memory. This will free more of the 640 Kb conventional memory for application programs.

Batch Files

A batch file is an ASCII format file with the .BAT extension that contains a list of DOS commands and application programs to be executed. When instructed, DOS executes each line in the file as if it was typed from the keyboard. Batch files can be invoked by typing the batch file's name. The most familiar batch file is AUTOEXEC.BAT which is executed whenever the system is re-booted. Batch files are basically rudimentary computer programs (Somerson 1988) that can perform loops, conditional statements and allow manipulation of variables.

Guidelines for Employing Batch Files

For optimal computer performance, batch files should be written for long, error-prone repetitive tasks. Batch files could be utilized, for example, to start a GIS or an image analysis program. This would allow the computer operator to use the GIS and/or image analysis program and install environment variables through the execution of a single command. In this way the end user's interaction with the operating system is minimal and thus less error prone.

What Is Computer Memory?

There are two kinds of memory, Random Access Memory (RAM) and Read Only Memory (ROM). The purpose of this section is to describe the differences between them and managing memory for GIS or image analysis operations.

ROM

ROM is usually contained in one or more chips and contains essential, permanently stored, software routines that help the system function. Included among these software routines are copyright information, tests, tables and error messages. ROM is non-volatile (permanent) memory, whereas RAM is volatile (temporary) memory whose contents vanish every time the computer is re-booted.

RAM

Computer RAM is usually comprised of three areas; conventional, expanded and/or extended memory. Conventional memory is the 1 Mb of memory that can be accessed by all IBM personal computers (Figure 1). IBM originally divided this available megabyte into 16 blocks each 64 Kb long. Of these 16 blocks, 6 blocks or 384 Kb were reserved for ROM, displays and Basic Input/Output Systems (BIOS) extension programs. This left 10 blocks or 640 Kb for DOS and its applications. The amount of 640 Kb memory that DOS requires increases with every new release. MS-DOS 4.01, for example, requires 40 Kb more RAM than MS-DOS 3.3 (Magid 1989).

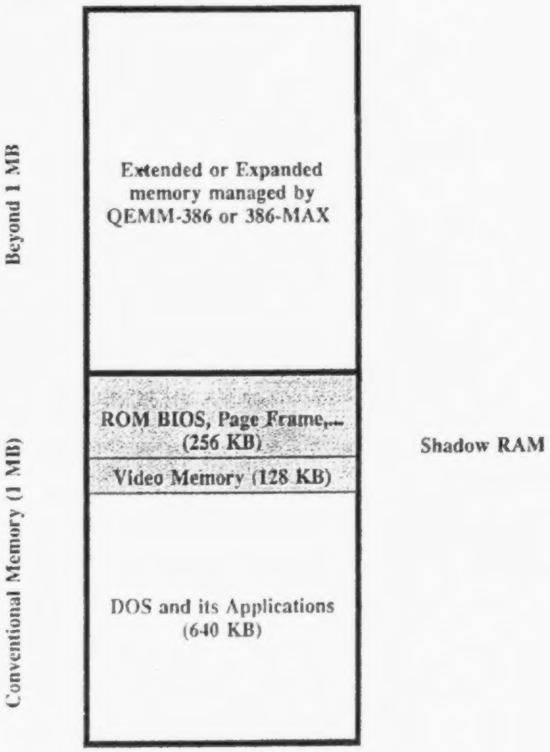
Beyond 1 MB
Extended or Expanded memory managed by QEMM-386 or 386-MAX
ROM BIOS, Page Frame,... (256 KB)
Video Memory (128 KB)
Shadow RAM
Conventional Memory (1 MB)
DOS and its Applications (640 KB)

Figure 1. Typical Memory Allocation on a DOS-Based Personal Computer

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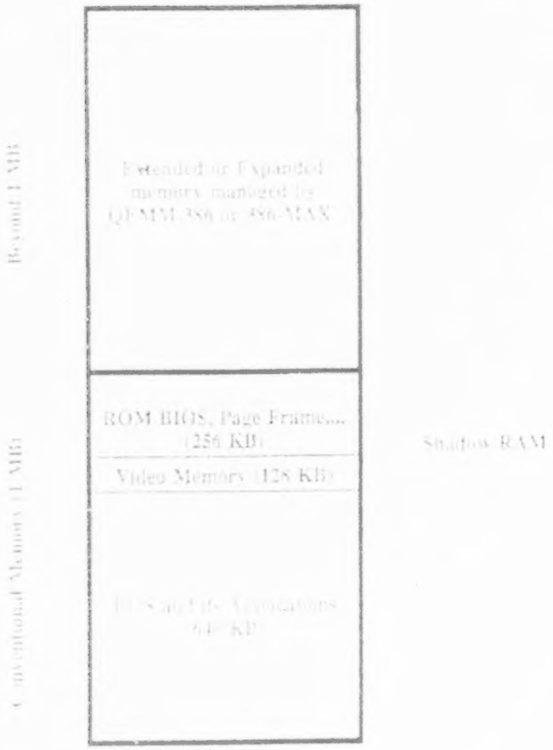
Beyond 1 MB
Extended or Expanded memory managed by QEMM-386 or 386-MAX
ROM BIOS, Page Frame... (256 KB)
Video Memory (128 KB)
DOS and Its Applications (640 KB)
Conventional Memory (1 MB)
Shadow RAM

Figure 1. Typical Memory Allocation on a DOS Based Personal Computer

Extended memory is the memory above 1 Mb and can only be accessed by 80286 and 80386 personal computers when running in protected mode. Current versions of DOS and most application programs cannot use extended memory because of significant differences between real and protected mode. A few vendors have written applications that take advantage of extended memory such as virtual drives, disk caches and memory managers. Virtual drives are sometimes called RAM drives and are usually installed through the VDISK.SYS or RAMDRIVE.SYS device drivers. Memory managers allow user definable conversion of extended memory to expanded memory.

Expanded memory refers to bank-switched memory, whose specification was developed by a consortium made up of Lotus Development Corporation, Intel Corporation and Microsoft Corporation. They named this specification LIM (LOTUS/INTEL/MICROSOFT) and the latest version is LIM V4.0 (Somerson 1988). Expanded memory can be mapped as pages into conventional memory. Data is mapped to extended memory through a 64 Kb segment near the top of the PCs addressable megabyte. This 64 Kb is used as a narrow doorway into expanded memory and is called a page frame. The page frame contains four smaller 16 Kb sections called windows. When an application that supports expanded memory needs more RAM, it could swap some information into expanded memory, and retrieve it later, by shuttling it back and forth through one of these windows. There is an increasing availability of programs and utilities that will operate either faster or more reliably if expanded memory is available. Examples of programs and utilities that will utilize expanded memory include LOTUS 1-2-3, PC Tools Deluxe and DOS buffers version 4.01.

Shadow RAM

If a computer has a shadowing option enabled, re-booting the PC causes pertinent ROM to be copied into the memory below 1 Mb or low RAM. The PC can then access a copy of these routines much faster than from the original contained on the ROM chip. 80386 and 80286 microprocessor-based computers can also use special software called memory managers that map ROM into the 384 Kb of RAM between 640 Kb and 1 Mb. In this way, shadowing is facilitated through software rather than hardware. Memory managers can also map extended memory into all the free areas of the 384 Kb range above the base 640 Kb. Making this memory available to DOS-based real mode programs. In effect, this memory becomes available for loading device drivers and TSR programs outside of the 640 Kb conventional memory.

Managing Memory for GIS and Image Analysis Systems

Most of the PC-based GIS systems have now reached a level of sophistication and capabilities that requires a large portion of the 640 Kb conventional memory to operate reliably. From a survey of 5 GIS and image analysis systems, the conventional memory requirements ranged from 540-580 Kb. The largest user of extended memory required upwards of 2.5 Mb of extended memory as a virtual drive for video display buffers. One system required 1 Mb of extended memory and one system suggests use of a memory manager to access available memory in shadow RAM. Another system is contemplating use of extended memory. The trend is in utilizing memory beyond 640 Kb, and the use of a memory manager such as QEMM-386 or 386-MAX is recommended for an optimal configuration. Memory management provides an additional benefit of freeing more of the conventional 640 Kb by moving device drivers, buffers, TSRs and disk caches into shadow RAM or expanded memory. This is particularly beneficial to those users who purchase systems with large hard drives.

Multitasking

Multitasking is when a system provides an applications environment which appears to the user to be performing more than one task at the same time (Krantz et al 1988). Multitasking allows several applications to share the single CPU present in personal computers.

DOS was designed to be a single-tasking environment, where the system can process only one segment of work at a time and only one application at a time. There are enhancements available to the DOS environment (e.g., DESQview386, Windows386, etc.) that support a multiple application environment. These enhancements use the 80386 virtual mode to turn the PC into several virtual machines, each of which can simultaneously run a standard DOS program. Being in a DOS environment, however, these enhancements come up against many of the limitations of the real mode environment of the virtual machines. It is very difficult to support useful multiple applications while fitting the enhanced environment, DOS, and the multiple applications all in 640 Kb. Some enhanced environments like DESQview386 map each virtual machine, which may use physical memory in the extended addressing range, into the DOS 640 Kb addressing range while the virtual machine is executing (Rosch 1989). In this way the 640 Kb barrier is broken. Unfortunately, virtual machines executing in a real mode environment do not protect one application from another and do not protect the operating system from the applications. These enhanced environments are a hybrid of DOS and protected mode operating systems.

The problems associated with DOS and the enhanced environments disappear when the personal computer is operated in a protected mode operating system like OS/2 or UNIX. These protected mode operating systems provide large virtual address spaces for each application. They utilize the protection mechanisms available in the protected mode of the 80286 and 80386 chips to provide protection between the applications and between the operating system and applications. Most importantly these operating systems allow multiple applications to execute concurrently. These systems were designed to be multiuser, multitasking environments. It is these protected mode systems that will give GIS and image analysis systems the computing power of a mainframe on the desktop. Protected mode systems, however, are not a panacea but merely the next step in the PC operating system evolutionary ladder.

Of five GIS and image analysis systems surveyed, one already has an OS/2 version available, and two others are actively planning releases. Three of these systems also have UNIX versions and another is pursuing a UNIX version in conjunction with another GIS software company. The trend is therefore obvious, DOS operating limitations have encouraged development in protected mode environments.

Hard Disk Management

The performance of a PC-based GIS or image analysis system can be greatly improved by efficient management of the hard disk. The purpose of this section is to describe management techniques that will deal with the problems of file fragmentation, file allocation table integrity, file management disk parking and backup.

File Fragmentation

When a file is stored on a hard disk, DOS splits the file up into cluster size blocks and starts looking for vacant parts of the hard disk to store these blocks. On a newly formatted hard disk all these blocks are contiguous. A disk that has seen massive file creation, deletion and editing activity, especially if the disk is nearly full, will result in DOS taking longer to find empty spaces. Typically, the file may end up being stored in dozens of fragmented clusters scattered all over the surface of the hard disk. This is known as file fragmentation. File fragmentation will cause a slow down in performance because the disk read/write heads must skip around the disk looking for clusters of data to assemble a complete file. If a hard disk is well organized and not fragmented, lost data recovery would also be possible since files are stored in consecutive clusters. There are generally two methods of unfragmenting of the hard disk. The first method is very drastic, cumbersome and time consuming. The hard disk must be completely backed up, reformatted and then the data must be restored. The second simple and recommended method involves the execution of disk optimizer software (e.g., available in PcTools, Disk Optimizer, etc.) on a regular basis.

FAT

DOS relies on a chart called the File Allocation Table (FAT) to store those clusters on the disk which are temporarily unused. The FAT also keeps track of where all the blocks that make up each file are located. The FAT is so important that most disks contain two identical copies, and updates both each time it adds, deletes or modifies a file. DOS directories also contain the address of each file's starting cluster. When DOS accesses a file, it uses the starting location in the directory and then uses the FAT to find each subsequent part of the file on disk. The original designers of DOS gave the FAT a maximum of 16-bit addresses, which meant that the largest possible table could have (216) 64 Kb worth of entries. Since each entry in the FAT chart was a sector 512 bytes long, the maximum size of any single DOS disk was 64 Kb 512 bytes = 32 Mb. The FDISK command of DOS version 3.3 allowed the user to partition one large physical hard drive into several smaller logical drives, each 32 Mb or less and each with its own drive letter. DOS provides the utility program CHKDSK.EXE to verify that the FAT is intact and that file clusters have not been lost . If CHKDSK is run in its 'fix' mode (i.e, execute CHKDSK/F at the DOS prompt), it will repair the FAT if it finds a problem. It is highly recommended to run CHKDSK habitually to verify FAT integrity, particularly for large capacity or frequently used hard drives.

File Management

Hard disks are capable of storing hundreds or thousands of files. If all these files were stored in a single directory, the user would find a slowdown in performance by DOS as well as suffering needless complications in locating a particular file. To overcome these barriers, the designers of DOS borrowed the concept of hierarchical directories (Figure 2) from UNIX and other main frame operating systems (DeVoney 1986). To understand these hierarchical or subdirectories the hard disk could be compared to a filing cabinet, which usually has several drawers or partitions. Inside each drawer are file folders or subdirectories. Each folder in the file cabinet contains material that applies to a particular subject. In similar manner, each subdirectory should contain related files. An accounting spreadsheet should not, for example, be contained in a subdirectory containing the GIS

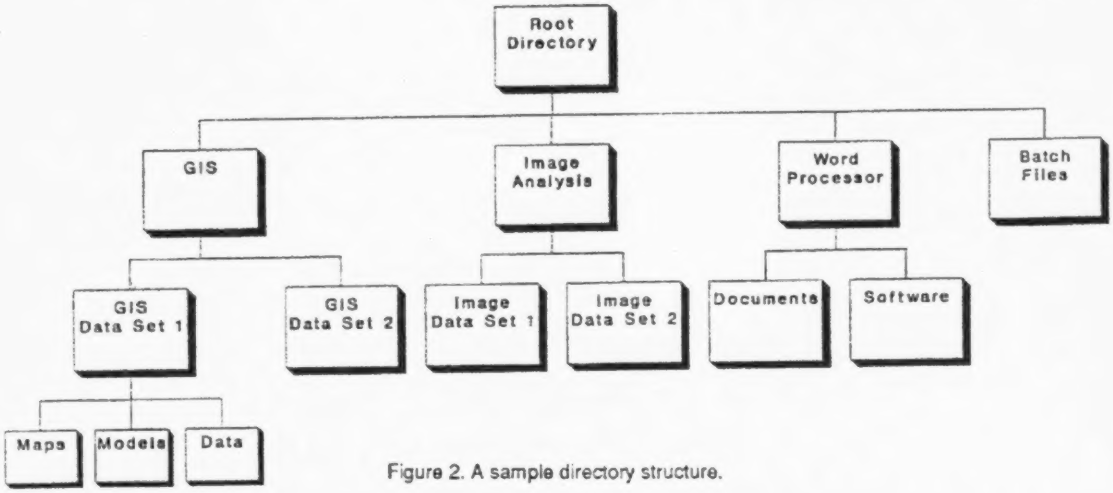

Figure 2. A sample directory structure.

or image analysis system programs. Organization of files will reduce the time the user and DOS will take to access a file or program. The organization of files will also increase security. For optimal performance, disk organization is essential, but more importantly, once a disk is organized keep it organized. This entails backing up files that are no longer needed and then removing them from the hard disk. Don't keep multiple copies of the same file on the hard disk.

In addition, the hard disk should be organized into subdirectories of files that are similar in nature. Naming conventions for files should also be adopted and standardized throughout the hard drive. This will enable the user to remember what a particular file contains in the future. It is also highly recommended that data files not be placed in the same directory as software files (Figure 2).

What is Disk Parking?

When the low level format is done on the hard disk it is recommended to create a dedicated landing zone. The landing zone is the place the read/write heads will position themselves over when the disk is inactive or parked. DOS will mark the landing zone clusters as bad and will not write data to them. This will mean that if the machine is bumped and the read/write heads touch the hard disk platters, data will not be destroyed. If the hard disk is *not* self parking, it is highly recommended to park the heads before the machine is moved or powered down. There are disk park TSRs available that will automatically park the disk whenever it is inactive for any time. It is recommended to leave the PC powered up all the time. Power surges generated by unnecessary on/off switching causes mechanical stress to the hard drive (Alford 1988). It is, however, necessary to dim or turn off the display monitor to avoid the possibility of phosphor burn-in which results in the screen image becoming permanently etched on the monitor (Alford 1988).

Backup

Expect hard drive failure! Typical hard drive life expectancy, measured as mean time between failures (MTBF), is 30 000-100 000 hours. This is equivalent to 3.4-11.4 years, but more importantly this is a mean rating since half of all hard drives will fail before the MTBF rated hour of operation. Alford (1988) stated "Remember, with hard drives it's not a question of *if* you'll lose your data but *when*." There are some disk errors that no utility program can correct. There is only one way to prepare for a hard disk disaster and that is to regularly backup the hard drive. An example of a good backup strategy is a generational approach which requires three separate, complete backups. The medium that contains these backups is then recycled by making the current backup on the oldest copy of the three. In this way, if the most recent copy of the backed up material fails, there are two supplementary copies that will facilitate the recovery of the lost data.

Summary

Achieving an optimal computer configuration has become increasingly difficult within the increasing memory requirements of GIS and image analysis systems, and the operating requirements of peripheral hardware and software. Technical information on hardware architecture and software requirements provide the basis for achieving an optimal configuration which will vary from machine to machine.

With the fast 80286 microprocessors now on the market, there has been some question about the suitability of 80286 or 80386-based microprocessors for GIS or image analysis systems. A rationale was given for 80386 computers based on an increased addressable memory, the ease of protected mode accessibility, memory management capability and downward compatibility.

Achieving an optimal configuration depends on the variety of uses the computer is being employed for. Third party software such as word processing, data base management, communications and statistical analysis for stand alone functions, or in concert with a GIS or image analysis system poses more constraints for optimal performance than a single application. This complex problem can be successfully resolved on a single PC platform by properly managing device drivers, TSRs, computer memory, buffers, disk caches, and employing batch files. Of particular value for managing device drivers is a public domain boot interrupt called CONFIG.CTL.

Guidelines to using TSR programs include selective use, placement into shadow RAM and placement into specific batch files to start the application that requires them. Seldom will one require all TSRs to be installed at start-up. The key is to maximize available memory for memory intensive applications.

In 80386 computers with a megabyte of memory or more, expanded memory managers such as QEMM-386 and 386-MAX allow user-defined conversion of extended to expanded memory. The programs and utilities that can operate in higher memory can then be placed accordingly.

Optimal utilization of batch files would include programs that initialize environment variables, parameters and install device drivers as they are needed rather than when the computer is booted. The memory otherwise required for these programs is then freely available to the operating environment and its applications.

Within certain limitations, multitasking within DOS for DOS applications can be achieved with programs such as DESQview and Microsoft Windows. The large memory requirements of GIS and image analysis systems has not effectively permitted multitasking of DOS applications and GIS and image analysis systems in a DOS environment. The increasing development and availability of GIS or image analysis systems within protected mode operating systems like OS/2 or UNIX, will allow true multitasking to be realized on the desk top.

Critical to maintaining optimal performance are the effects of day-to-day operations and employing good hard disk and file management practises. File fragmentation is a frequent problem and contributes to both increased access times and wearing of the hard disk.

Backup, backup, backup! How often have you heard this? There is no replacement to having recent backups if a failure occurs.

Optimal configuration of a PC for GIS and image analysis operations can only be achieved by application of established file, system and memory management techniques. To apply these techniques, there must be more than a cursory understanding of the hardware platform, software applications and operating system environment limitations.

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A Survey of GIS Use of Forestry Applications in Canada

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Abstract
A brief mailout survey questionnaire was initiated in late 1988 to gather data from a cross section of Canada's institutional GIS users in the Forestry and Natural Resources sector. The survey investigated the present and anticipated GIS technology used, the applications, the implementation issues, GIS issues and problems foreseen. The data collected indicates the dynamic nature of forestry GIS users and the potential growth of this technology within all forestry related organizations throughout the country.

Introduction

In the last few years, the potential scope and importance of GIS technology for forestry has grown steadily. In attempting to document this area, a survey was conducted by a mail out questionnaire to sample GIS forestry activities across the country. In this respect, time and survey resource constraints narrowed the survey's audience. However, the forty surveyed respondents represented all provinces and major federal GIS forestry groups throughout the country. The survey's goal was to investigate the following:

- GIS technology being used,
- the extent of implementation/application areas,
- potential GIS issues/problems of users, and
- trends or implication of trends for GIS technology.

The surveyed sites varied in types of applications, life cycle stages and size of GIS facilities. The percentage of surveys returned was approximately 65%, which indicates a very strong interest in GIS forestry activities across Canada. Most returned surveys were fully completed which addressed several key GIS topics:

- mandate,
- current and future GIS uses,
- user's implementation,
- operational problems and difficulties,
- GIS education,
- organizational issues,
- supplementary data (remote sensing), and
- future GIS applications and products.

As well, many operational users added their own inputs, chief being the development of a newsletter to communicate ideas and events of specific forestry related GIS work, research, GIS methods and techniques which should be initiated. The strongest comment from the survey was the importance of operational and organizational awareness for GIS education. As GIS applications have gained strength, the importance of GIS information handling and output has become critical for any agency, thus, the education of GIS staff becomes vital.

Most GIS respondents who replied had fairly small staffs, with an average just over seven staff members per GIS facility. Though not large in numbers, they play potentially vital roles for their own organizations. Many of the surveys complained that their GIS budgets did not adequately meet their operational needs. Additionally, they lacked sufficiently trained staff, which tells one that current GIS facilities are encountering perceived staff resource limitations in their operations. This may be related to the response that only 35% of the respondents had a formal GIS operating mandate to implement their work strategies. In the majority of cases, the area of interest of the group, i.e., forest inventory, provided their operational mandate. In the survey's eleven GIS categories listed, the largest current GIS usage of respondents was in the forest inventory category (60%). The largest future usage of respondents came from forest data integration (70%). A breakdown of the current and future applications is listed in Table 1. Most users indicated multiple GIS uses in their systems.

Table 1.

GIS USE	CURRENT USE %	FUTURE USE %
FOREST INVENTORY	60	40
HARVEST SCHEDULING	15	55
TRANSPORTATION PLANNING	NA	25
MANAGEMENT PLANNING	30	55
FOREST MODELLING	25	65
RESEARCH & DEVELOPMENT	25	45
FOREST ECONOMICS	5	40
HARVEST STUDIES	5	35
POLICY STUDIES	5	55
ENVIRONMENTAL ASSESSMENT	10	50
DATA INTEGRATION	50	70
GIS TASKS PER SITE	2.64	5.85

In the priority ranking of GIS uses, roughly 40% of respondents did not have any future uses ranked. However, the top rank for current usage was in forest inventory work with 40%. The future ranking, though not as well answered, had three dominant use categories. Data integration scored 33%, while forest inventory and modelling each scored 15%. Thus, modelling and inventory seem strong future topics of interest but data integration work will dominate according to users. New application areas perceived will be in policy studies, management planning, and harvest scheduling, with 55% of users identifying these topics as future application areas.

Presently, 2.65 GIS applications run at the average respondent facility. From the future GIS application uses reported, each facility will average 5.85 tasks. This would be approximately a 220% increase in applications. How this type of usage will affect the work of future forestry agencies can only be surmised.

It was clear that the ESRI-type GIS technology presently dominates, as it accounts for approximately 60% of existing systems. Next was Tydac Inc., with 25% of the sites, and the rest of respondents had no one key vendor's GIS technology. In total, eight GIS software products were identified in the survey. Of the four types of hardware listed in the survey of mainframe, mini, micro or service bureau environments, the microcomputer dominated with 50% of the respondnts using them as their GIS processing platform. No single computer vendor stood out as the favourite, as clones and namebrands were listed equally. According to the survey, most sites were started between 1985-87. Over this period, about one third of the sites established their systems. It should be noted that several respondents indicated the development of new systems over the past year with ongoing development plans for the next few years. In approximately 30% of the responses, new GIS systems will be implemented in the next three year period.

In conjunction with the implementation process, the development of specific in-house software applications was questioned. Approximately 50% indicated that they were using custom in-house software. GIS user software development includes forest data queries of overlaid map data, database labelling, updating and simulation methodologies as well as user programs. Problem areas were identified as hardware problems at 25% of the sites, software problems at 45%, and that training /technology transfer problems occurred at 60% of the sites. These two areas formed a tandem response, indicating that staff GIS training and the use of GIS technology are linked for many GIS operations. Related to these was GIS education and its role in forestry programs. In 70% of responses, the opinion was that mandatory GIS education by forestry schools should be implemented. As well, 55% felt that forestry school graduates did not have the necessary knowledge and GIS skills to aid them in their work. Here, it would be critical to identify the type of training, but the overall opinion was that forestry GIS education is not adequate. Presently, undergraduate forestry faculties in Canada offer collectively only five forestry-specific GIS courses by calendar listings. As to forestry input into working with GIS, no one clear answer came from the survey, 45% replying no, 35% replying yes, and 20% were undecided. Attitudes towards GIS technology vary with each site. The major GIS difficulties described by users in the survey were:

- organizational (operations between central and unit groups.),
- database integration of various data sets desired.,
- data capture and data precision problems,
- project management of numerous projects, and
- technology transfer of GIS to operational users.

Major issues identified by users as being detrimental to the success of their GIS facility from the survey are listed in Table II.

Table II

ISSUE	RESPONSES %
Budget/financial support	55
Staffing support	50
Technical support	25
Organizational	20
Mandate	15
Managerial	15
Poor vendor selection	15

Summary and Conclusions

In looking at the overall survey results, it is clear that the human and technical resources issues play the most vital roles in the successful operation of a GIS facility. It is especially noticeable that securing the financial support to fully implement a GIS and maintain and train its staff was the major issue faced by the surveyed users. The organizational, and managerial and political issues, though present, are overshadowed by the operational costs to run current GIS systems. It is important to note the planned future GIS applications of existing GIS users. Fundamental to all future work will be multiple data sets in compatible and standardized formats. Also important will be staff who can identify and work with various data sets and applications between GIS systems. Besides new operational factors, the education of GIS forestry staff is perhaps the key to success, judging from its importance to the current users.

The survey also indicated that maps were not the only forestry information source as remote sensing and photographic data products now supplement user data. Increasingly, these products have value-added importance for a GIS user in the presentation of problems and/or results. Presently 75% of the GIS facilities or users surveyed use supplementary digital remote sensing data. This data is applied to data integration, forest inventory, change detection and forest assessment work. Yet, despite the advanced GIS technology, several survey respondents pointed out that GIS is only a tool and foresters must recognize this in order to achieve their goals, rather than letting the technology lead them. Current users recognized the need for several improvements in the current GIS tools offered. Major areas of improvement listed were:

- more efficient data capture techniques,
- improved interfacing between other GIS systems and image processing systems (remote sensing applications),
- data exchange and data encoding standards,
- national GIS standards for forestry,
- compatible data sets for sharing information,
- economical service bureaus for data capture contracting, and
- a GIS newsletter for current forestry applications and news

Several of these items are being pursued by forestry professionals and may be resolved if the envisioned increase of forestry GIS occurs as users expect. From the survey, a few trends are clear. Firstly, current GIS forestry technology has been adopted in provincial forestry agencies. All provinces have established or are establishing their own GIS programs. Secondly, current GIS users have a desire for compatibility between systems in order to share and develop compatible GIS data sets. As well, the use of remote sensing products for forestry applications is strong and will continue with future data integration work envisaged by users.

In operational terms, a better management of forestry resources by GIS methods will take time, according to users, who have to solve perceived and real problems between central and district forestry offices. In educational terms, more geographic information system knowledge and data knowledge will be necessary to meet the expected workload. Here, one can hope that new GIS products will promote a better user interface and get rid of misinformation.

Most respondents see GIS as a tool which must address their real data needs, which are best understood by those experienced in forestry. Topics such as forest modelling and data integration seem destined to be developed in-house, judging from the survey's data. In order to achieve the types of GIS tasks mentioned by users, increases in budgets for training and system implementation will depend upon the particular GIS task and its priority within its own agency.

Even though a forestry agency has GIS hardware and software, there remains the problems of GIS data capture, compatibility, conversion, and standardization. In a good portion of the surveys, a strong interest in sharing data sets and GIS applications was put forth. It seems feasible, with GIS forestry developments, that a new GIS user publication will emerge to provide communication among the interested user groups.

Overall, a great range of experience was encountered within the survey, with a variety of GIS applications, technologies and states of GIS implementation across the country. Consequently, the forestry GIS field seems destined to grow and develop many offshoots over the next five years as reflected by a current sampling of existing GIS forestry sites. It will be a very rich and challenging time judging from those surveyed today.

Global Perspectives

Session E4
Global Perspectives - 1

GIS in the Southern African Context

The Use of GIS in the Resolution of Land Use Conflicts in Tasmania

The Global Forest Inventory - Measurements using Satellite Imagery and GIS in Amazonian Forests

GIS'90 Symposium

Vancouver, British Columbia
March 1990

GIS in the Southern African Context

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Abstract
The nature of two regional planning tasks for which GIS has been used by the Institute are outlined. In the case of Maputaland, the value of a digital system for the assessment of resource development initiatives is set out, as well as the reasons for the failure to fully utilize project results in the planning process. The other work, in the alpine zone of Lesotho, underlines the value of GIS to help predict man's impact on fragile resource systems. We assert that planning action to reduce conflicts in southern Africa will not succeed without the utilization of GIS in decision support systems.

Introduction

The first generation efforts at the Institute of Natural Resources (INR) to establish GIS are reflected in this paper. The INR was established in 1980 as an independent non-government organisation affiliated to the University of Natal to provide a planning and consultative service to the people of the Natal/KwaZulu region, a region characterised by a First/Third World dichotomy. The Institute's GIS Programme was formulated to identify information needs and create suitable decision-support systems (DSS) to resolve key resource and development problems within this region. Two projects are considered to highlight the problems and prospects for successfully implementing GIS, not only at the Institute but generally in southern Africa.

Wellar (1989), in an erudite discourse on GIS knowledge, highlights the contributions, largely anecdotal rather than analytical and particular, as opposed to general to the literature. The apparently endless one-off or case study GIS reports provide 'lots of noise, little signal'.

It is the contention that in putting forward these case studies within their African context, important philosophical issues and principles governing the use of GIS emerge. The resultant insights reflect the pragmatism governing early GIS work at the INR, but on reflection, such an approach is vindicated by the inherent newness of the technology in the region and the ever-green desire to 'make it work' that besets many researchers.

The Context for GIS in Southern Africa

A recent issue of Finance Week (December 14, 1989), in reviewing the previous decade, made the point that ten years ago in South Africa there were, *inter alia*, no fax machines, push-button telephones, Black Trade Unions, toll roads, Automatic Teller Machines, legal sex and marriage across the colour line, open beaches and AIDS. To this list could be added GIS.

GIS has become a 'band wagon' technology only in the latter 1980's in southern Africa. Previous work, for example, that of large municipalities, public organisations such as Geological Survey, and the Surveyor General's office, reflect concern with digital mapping, not necessarily equitable to GIS with its inherent characteristic of intelligent mapping and analysis.

After 1985, GIS gained recognition as an appropriate technology in areas such as water (Department of Water Affairs) and municipal management (cities of Cape Town and Johannesburg). The Council for Scientific and Industrial Research (C.S.I.R.) also gave credence to the technology with the establishment of a GIS unit. The founding of NAGIS, the first working group to foster GIS, occurred in 1986 in Natal, the year in which the INR also officially instituted its GIS Programme. Although GIS had an airing at EDIS '87, the Conference of the South African Society for Photogrammetry, Remote Sensing and Cartography, it was only in 1989 that the first conference dedicated entirely to GIS in southern Africa, SAGIS '89, was held.

It is against this backdrop that the Institute undertook the establishment of GIS's for regional planning in Maputaland, Northern Natal (1987) and resource management in an alpine region of the Kingdom of Lesotho (1988). Previous work had focussed, for example, on GIS to foster local development planning in Biyela (Fincham and Berjak, 1988, 1989), the assessment of the spatial and temporal dimensions of soil erosion in Northern Natal (Watson et al, 1987) and a resource atlas for Natal/KwaZulu (Fincham et al, 1989). Technical development of the system has been addressed by Berjak and Frankland (1989).

GIS and Regional Environmental and Development Initiatives : The Maputaland Case

Establishing a GIS to provide an overview of resources and analyse relationships between factors that impinge on the development process in Maputaland has highlighted a number of issues.

Maputaland, lying to the south of the Mozambique border, and encompassing an area of approximately 7 000 km^2, has a history of intervention by 'outsiders' to bring about so-called 'development' (Derman & Poultney, 1987). It is a sorry history of plan formulation, intervention on the ground and the invariable failure of the project(s) or scheme(s). A groundnut and a rubber scheme are examples of two such failures. There is, however, no doubt that increasing pressures on the natural resource base, a rapidly expanding population and the strategic significance of the region make development and conservation strategies a matter of urgency. It is a situation in which conflict resolution between various development agencies, regulatory bodies and the needs of the local inhabitants has to be engineered.

The INR was asked to develop a GIS as a means of promoting a longer term view of intended development and conservation projects and their likely impacts. The INR set up a GIS at the start of 1987. Inherent in the system is an attempt to overcome the cyclical process of implementing schemes which invariably fail and from which few lessons are learnt for future initiatives.

The GIS technology appeared to provide the capability of considering the impact of alternative strategies. In the case of Maputaland, GIS represents the development of in-house algorithms and their associated implementations. The task assigned was one which called for a technical solution to a computational and data management problem.

A continuous or vectoral,as opposed to raster model has been developed and factors which have been captured include: population distribution, areas with potential for nature conservation, soil types and riverine features. The factors then become layers of information in the data base and can be compared with each other, facilitating new information and vindicating the GIS approach to setting up a decision support system.

What is now emerging from the increasingly broad data base (developed at 1:250 000) is that comparisons of various factors provides a critique of potential interventions and indicates the impact that such interventions can have. For example, various agencies have their sights set on a fertile zone of Maputaland called the Makatini Flats which encompasses the floodplain of the Pongolo River. Two development agencies, one in crop production, the other in nature conservation, have nominally reserved a large proportion of these Flats for their expansion programmes.

Within the GIS these proposals can be matched with other factors in the system (notably, population distribution and density) and the implication of the proposals evaluated. By asking the "What if?" questions, the system has indicated that these proposals could result in local population relocations of considerable proportions. Examination of the resources of the rest of Maputaland suggest that these people would be unlikely to find suitable alternate resources to support their traditional life-styles. The GIS is thus able to show the inherent flaws in these development proposals.

The GIS staff have noted wariness on the part of agencies and those involved in Maputaland development to consider the technology as relevant to their 'approaches' to problem resolution. Vested interest in the 'rightness of one's current approach' is a powerful motivating force and when it is tied to having to absorb the merits and pitfalls of a new technology, then adoption of that technology a as part of the way people tackle problems will take time.

Scarcity of data on key variables has proved to be another problem of the Third World context in which the GIS operates. This lack of information, rather than the technology itself, is a major limiting factor to the more rapid acceptance of GIS within the development and conservation arena.

Three general principles emerge from the Maputaland GIS:
1. GIS provides the technical capability to answer "What if?" questions.

Prior to the setup of the system, the impact of crop production proposals on population relocations could not have been adequately assessed, nor the likely conflict between nature conservationists, the crop productionists and the local inhabitants.

2. GIS potentially offers a means for promoting holistic planning and conflict resolution.

Agencies invariably push their own causes without seeing the wider implications of their work. The GIS throws into stark relief geographically defined conflict zones.

3. The serious lack of data in Third World situations hampers strategic planning.

The lack of vital data (the demographic data, although good by African standards, is still very inadequate) is an issue which faces development initiatives in most Third World countries. It is essential that this issue is addressed in setting up GIS. This means that one will have to:

(i) cost in the expense of data collection above and beyond data capture,
(ii) learn to use surrogate variables,
(iii) develop modelling tools which will enable one to use auxiliary variables to extend and map expensive or patchy spatial data sets.

Resource Management in the Alpine Zone of Lesotho
Lesotho, with an area of over 30 000 km2 and a population of 1.3 million, is an independent landlocked country. Nine tenths of the country consists of highlands with peaks such as Thabona Ntylenyana rising in excess of 3350 m.

The ambitious Lesotho Highlands Water Project (L.H.W.P.), a complex of dams and tunnels to store and transfer water as well as generate electricity, has been welcomed with great optimism because of its ability to generate employment and provide a much-needed injection to the Mountain Kingdom's economy. The L.H.W.P. is situated downstream of the alpine zone in eastern Lesotho and, because of its proximity to the industrial complex of the Witwatersrand area, will have an assured market for its water into the Twenty-First century.

The GIS was set up by the Institute as part of a project to provide policy guidelines for the Lesotho Government for managing part of the eastern highland or alpine region of Lesotho. Management for this region was seen as vital because of its fragile nature, the pressure on it from pastoral activities, the concommitant threat of soil erosion, and its role as a water resource area for the L.H.W.P.

The GIS was to provide a single geographic data base to assist the programme co-ordinators draw together the results from numerous sub-projects concerned with the human use, hydrology and vegetation of the project area.

The GIS also had to be designed in such a way that it could be readily transposed into Lesotho and function as a long-term system for updating, maintaining and analysing data within the system by Lesotho. Training of Lesotho personnel was undertaken from the project's inception and added a further dimension to work undertaken.

To date, the initial system has been set in place and the incorporation of geo-referenced material from sub-projects successfully assimilated. However, in reviewing the draft policy statement to the Lesotho Government (Government of the Kingdom of Lesotho 1989), it is evident that GIS has not been fully institutionalised within the proposed strategic decision support system (DSS).

Given the pioneering nature of the overall study, the co-ordinators, understandably, failed to identify the comprehensive role GIS should have played in the DSS. A major problem, as many other case studies have revealed, is that the GIS remained technology-driven rather than user-driven.

A further principle emerges from the Lesotho work: GIS must be an integral part of the DSS from the outset of a study. In this case, GIS still functioned as an 'add-on' co-ordinator of data. Figure 1 illustrates the GIS as an 'add-on' in which the data are problem specific.

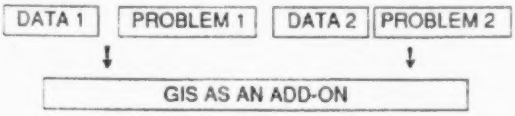

Figure 1. GIS as an Add-on. (After Piper, S. 1990.)

A preferable concept is shown in Figure 2, in which GIS is an integral part of the DSS, and problem-independent data are used by many problems and integrated into the DSS.

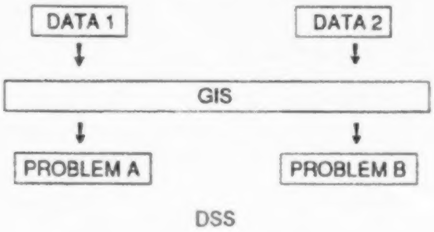

Figure 2. GIS as integral to the DSS. (Ibid.)

Fortunately, the merits of the Lesotho system, with its ability to model alternative scenarios with the existing data, has continued to receive support from key organisations within Lesotho, particularly the Range Management Division of the Department of Agriculture. A training programme is in force and there is every opportunity that the DSS for range management will continue with GIS as the driving technology. Furthermore, the long term possibility to link the alpine work with that of the L.H.W.P. remains a possibility. The possibility to develop a regional computer networking system for management is an envisaged goal.

Assessment and Conclusion

GIS technology is in its infancy in southern Africa. There is little doubt that as the scarcity of natural resources become more apparent and demand rises, managers of those resources will need to improve their access to and manipulation of environmental data.

Furthermore, from a development perspective, the urgent need to improve or maintain living standards will require current information and the ability to consider the likely impacts of alternative development strategies.

The studies reported on in this paper continue to reflect, in part, the anecdotal rather than analytical and the particular rather than the general approach (Wellar, 1989) to furthering knowledge of GIS. However, knowledge will always be furthered by intuition, common sense and everyday experience as well as through the establishment of principled research.

There is, however, no doubt that the attainment of a robust and rich GIS knowledge base will only emerge if more philosophical rigour accompanies particular GIS developments. As such, the notions of conceptual modelling depicted by Williamson and Hunter (1989) have considerable merit.

The area of institutional commitment to GIS remains a serious problem as these case studies show. An important initiative at the Institute, the creation of a Rural Areas Water Plan (RAWP) for a major proportion of the Natal region, will adhere forcibly to modelling procedures identified by Williamson and Hunter (1989).

The grave shortage of technical, managerial and subject-specific skills will continue to haunt the successful implementation of GIS in southern Africa. A possible solution exists, in the case of projects undertaken by the Institute, of providing both conceptual and technical backup to local GIS development initiatives. To this end, the work in the programme has been divided as follows:
(i) project conceptualization, problem definition and system design,
(ii) training,
(iii) data capture.
Such liaison suggests a route of distributed production and processing which will make the best use of limited personnel skills.

Dangermond (1988) has suggested three goals for a GIS:
(i) to increase productivity,
(ii) to better manage data and avoid duplication of effort, and
(iii) to facilitate effective planning.

While the first generation of projects discussed in this paper have had limited success in achieving these goals, they have provided insights into important problem areas. Greater philosophical rigour and a stronger adherence to establishing the principles governing successful GIS implementation will mark the next generation of Institute-related GIS work.

Acknowledgements

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The Use of GIS in the Resolution of Land Use Conflicts in Tasmania

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Abstract

The acceptance of the recent nomination of twenty percent of the State of Tasmania, Australia for inclusion in the World Heritage List, brings to a culmination many years of debate over land-use.

This paper describes the use of a Geographic Information System by the Forestry Commission, Tasmania to examine resource and environmental values to formulate land-use decisions. These decisions are largely reflected in the selected World Heritage boundaries.

Introduction

Tasmania is the smallest state of the Commonwealth of Australia, with an area of 6.8 million ha. and a population of approximately 450 000 people. Nearly 50% of the State is covered with forest of which three quarters is publicly owned. Forests are mostly native eucalypt. They include the tallest hardwood trees in the world. Ten per cent of the State is covered by cool temperate rainforest. There are small areas of exotic softwood plantations of mainly radiata pine.

Forest industries in Tasmania are worth $1 billion to the economy and directly employ 5.6% of the workforce. Tasmania is the largest contributor by volume to national forest production from 9% of the nation's forest area.

A significant part (20%) of Tasmania is inscribed on the World Heritage List. The Tasmanian Wilderness World Heritage Area of 1 374 000 ha. was accepted in 1989 due to its outstanding cultural and natural values. Most of the World Heritage Area is or will be declared a National Park resulting in a total area of reserved land managed by the State's park service of 2 200 000 ha (32% of Tasmania). Figure 1 shows Crown land tenure in Tasmania.

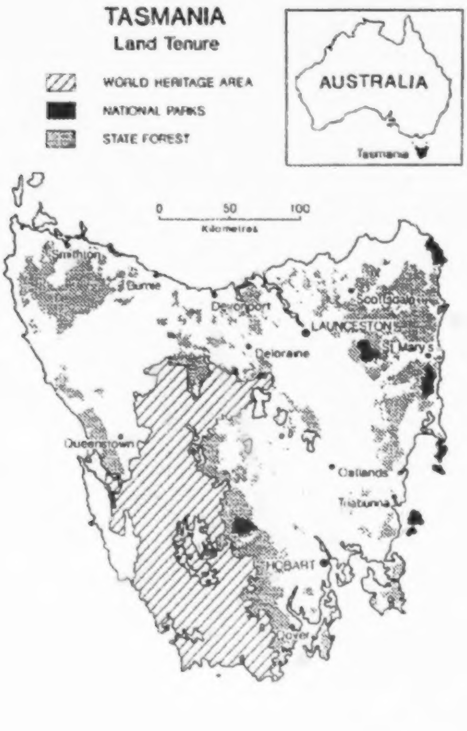

Figure 1

The listing of the World Heritage Area brings to a culmination many years of debate over land-use in the western part of the State. Much of the land was previously State forest or other public lands on which the considerable forest and mineral resources of the area were available for utilisation.

This paper describes the background to environmental debate on land use in the region and how a geographic information system was used to evaluate the impact of different options for wood production and land preservation on that part known as the Southern Forests.

The Southern Forests

The Southern Forests region of Tasmania is an elongated strip of land about 20 km wide and 85 km long in the central and southern part of the state lying between the infertile Precambrian quartzite mountains of the west and the drier settled agricultural areas of the east. The area of land to the west of the Southern Forests planning area is part of the Southwest National Park. Figure 2 shows the location of the Southern Forests planning area.

It is characterised by a rugged topography, high rainfall (1000-3000mm) and diversity of vegetation. The tallest stands of hardwood in the world grow here, notably *Eucalyptus regnans* which has been recorded to grow to almost 100 metres.

Since European settlement of Tasmania in 1803, the Southern Forests have been a major focus for the island's development, through the exploitation of the forest resources.

The Southern Forests continue to be an important source of timber supplying many sawmills, a newsprint mill, a pulp mill and two export woodchip plants.

The Southern Forests also contain many significant natural and cultural resources some of which are not compatible with wood production uses. In particular, the preservation of remaining areas of oldgrowth tall eucalypt forests and the maintenance of existing wilderness quality and quantity are highly valued aims of the conservation movement (Harwood and Kirkpatrick 1980, Ziegler 1983). Southwest Tasmania's wilderness areas are one of only three large temperate wilderness areas remaining in the Southern Hemisphere.

Land Use and Management in Tasmania

Use of Crown land in Tasmania is decided by State Parliament through Acts of Parliament. There is no land-use authority to examine competing claims for land use.

State forests are Crown lands managed by the Forestry Commission, Tasmania under the Forestry Act 1920. Primarily, the Commission is charged with management for a sustainable supply of wood to industry, but practices multiple-use management for the conservation of flora, fauna, recreational, scenic and other environmental values.

The Commission is responsible for the planning for management of all land under its control. It does this formally

Introduction

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The Southern Forests

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Land Use and Management in Tasmania

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through a Working Plan which specifies the area and volumes of timber to be harvested over a period of time, and for some areas through a Forest Management Plan which specifies which parts of a Planning area are to be used for various purposes and how they are to be managed. The later plan is required to follow a public and interdepartmental comment process.

Land Use Planning and Conflict in the Southern Forests

Most of the Southern Forests were dedicated as State forests in the 1920's. Significant parts of the area to the west of the Southern Forests were declared National Parks in the 1960's and 1970's. These parks were part of the 1982 World Heritage Nomination in Tasmania.

Although the parks protected many important values and features, there were significant areas of high conservation and recreational value excluded, as they were within State forest. Of particular note were areas of high wilderness value and significant unlogged stands of tall eucalypt oldgrowth forest. Representation of these forest types in the existing State Reserve System was low (Forestry Commission 1987, Kirkpatrick et al 1988).

Listing of these forests on the Register of the National Estate by the Australian Heritage Commission and the listing of the adjacent National Parks on the World Heritage List in 1982 plus a growing focus by the conservation movement on protection of remaining wilderness areas and National Estate forests led to the need for a detailed evaluation of the areas resources and plans for future management.

The Forestry Commission's Geographic Information System

The Forestry Commission began investigating the acquisition of a computerised GIS in 1982 in response to a need for more powerful techniques to store, update and analyze the ever increasing natural resource data it was gathering.

The Commission purchased the ARCINFO software from Environmental Systems Research Institute in late 1984 and currently runs the software on two PRIME 4050 minicomputers, each with 16 megabytes of CPU. Disk storage is currently 2.7 gigabytes. There are eight graphics terminals (Tektronix 4200 series), six digitizing tables and three plotters. In addition there are ten microcomputers with Teletronix emulation and more than 30 text only terminals all connected through an Ethernet network (Fenn and Weston 1989).

GIS use in Planning for the Southern Forests

The first major project for which the Commission's GIS was used was the production of a new Forest Management Plan for the Southern Forests. This area provided a complex array of overlapping resource and environmental values.

The planning method involved

1. Selection of land uses to be evaluated

Evaluation of non-wood use was limited to those that were seen to be incompatible to some degree with wood production. This greatly reduced the cost of data collection and simplified analysis and presentation.

Four uses evaluated were:
- wilderness
- landscape
- flora conservation
- recreation

2. Selection of the Land Unit for Evaluation

The basic logging unit (coupe) was chosen as the land unit for comparison of wood and environmental values. This enabled the outcome of the planning process to be directly related to operational boundaries in the field.

Definition of future coupe boundaries enabled the ready identification of areas not practicable to be harvested at an early stage, thereby further simplifying the evaluation.

Areas already developed for wood production were also identified at this stage and removed from further consideration.

In this way the total planning area of 165 000 ha was reduced to an area of 32 000 ha which has undeveloped potential wood production value.

3. Resource Evaluation

Each of the 342 provisional coupes within the conflict area was allocated a wood value and a non-wood value on a ranking of 1-4.

Wood values resulted from
- estimated recoverable volume
- estimated site potential
- roading cost
- topography and harvesting difficulty

Volume and site potential were derived from digital forest-type maps which record species, height and stand density classes interpreted from aerial photographs.

Non-wood values were derived from previously prepared manual maps resulting from detailed studies of:

- wilderness - derived from estimates of remoteness and naturalness of the coupe and the impact of harvesting the coupe on adjacent areas of high remoteness and/or naturalness.

- landscape - derived from evaluation of whether the coupe could be seen from remote viewpoints within the recognised adjacent wilderness area, and whether the view is part of a natural or non-modified viewshed (Chetwynd 1989).

- flora conservation - derived from information on occurrence of rare species, whether the coupe forms part of a flora conservation proposal or whether harvesting would pose a risk to nearby fire sensitive communities (Williams 1987).

- recreation - derived from an assessment of the impact on bushwalkers using a recognised walking track.

A series of classification rules were developed to rank coupes into the four wood and four non-wood classes to simplify analysis of the combinations.

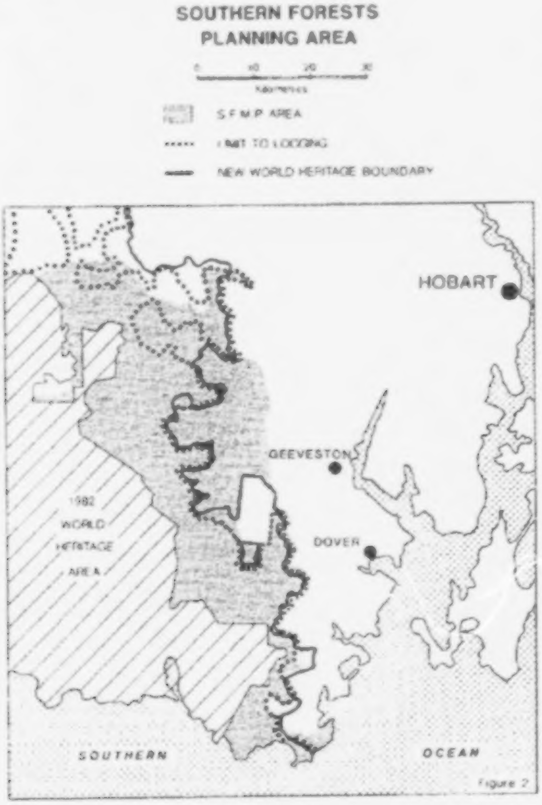

Figure 2

4. **Analysis of Options**

A series of GIS generated maps were presented to managers indicating different boundaries separating wood production areas from non-wood production areas, and the potential impact on available wood resource and loss of environmental values.

5. **Decision**

Senior management used the options to derive a 'limit to logging' line for the Southern Forests. A draft Forest Management Plan was then prepared for public comment. Proposed management zones are shown in Figure 2. Details of the planning process are described in Ingles and Wood (1987).

Lemonthyme and Southern Forests Inquiry

Whilst the planning process described above was going on, timber harvesting in the Southern Forests was continuing. There was much public concern over the extension of new roads into the Farmhouse Creek and East Picton areas, approved under previous management plans (Forestry Commission 1983, 1986).

A major Environmental Impact Study on the export woodchip forest industry was conducted in 1985 (TWE Study Group 1985) which lead to a Memorandum of Understanding (MOU) between the State and Federal Governments over logging in various National Estate areas.

The MOU allowed the planned logging to go ahead, subject to protection of National Estate values. However, conservationists staged a series of protests in the forests which received national media coverage. They continued to press for fundamental changes in forest land use (Rolley 1989). Responding to this pressure, the Federal Government, facing an election in which the green vote was crucial, set up a new legislative initiative, The Lemonthyme and Southern Forest Inquiry Act 1987. The Act halted all forest operations in a defined area for 12 months while an inquiry was held into whether the area had World Heritage values and whether there were feasible alternatives to harvesting these forests. The Inquiry Area included most of the Southern Forests planning area.

The Inquiry handed down its decision in May 1988 recommending that only 10% of the inquiry area had World Heritage values (DASETT 1988). This was unacceptable to the conservation movement and politically unacceptable to the Federal Government, who in November 1988 negotiated an agreement with the State Government to nominate 71% of the Inquiry area for World Heritage in return for financial compensation.

In most part the boundaries of the additional World Heritage Area in the Southern Forests followed the limit to logging line determined by the Forestry Commission's planners. In other parts of the Inquiry area, where similar planning work had not been carried out, substantial areas of planned wood production forest were included and some difficult management boundaries resulted.

Throughout this political process which took several months of negotiation and involved Federal Cabinet in many days of heated debate, the value of the Commission's investment in the GIS was apparent.

Federal and State politicians and bureaucrats asked frequent and often complex questions over the area, timber resource, wilderness and tall forest values of particular pieces of ground, in an attempt to resolve the debate with minimal impact on the resource available to forest industry and hence jobs. The GIS enabled relatively rapid and accurate responses to be made.

The result was a boundary that was for the most part manageable and preserved significant environmental values. Resource loss overall was about 9% of the State's sustainable yield of sawlogs. Within the Southern Forest net resource loss was lower.

The World Heritage Nomination

The recent nomination of the Tasmanian Wilderness World Heritage (1989) area was even larger than the November 1988 proposal. This was due to a change in Government in Tasmania from the pro-development conservative Liberal Government to a Labor-Green Independents alliance who came to power in June 1989 with an Accord which included additional World Heritage Area nominations. Again, areas added in the Southern Forests were consistent with the Commission's planning options. (See Figure 2)

Most of the defined non-wood zone in the draft Forest Management Plan has become part of the World Heritage Area, leaving the Forestry Commission to manage the State Forest wood production zones.

Conclusion

The Forestry Commission's purchase of a GIS has enabled forest and land-use planning to be conducted to a level of sophistication not previously possible. Complex sets of data have been able to be efficiently used to present clear information to managers.

The Commission's use of GIS reports and maps during a public and legalistic inquiry into land-use considerably enhanced the public and professional image of the Commission.

Data capture is being extended statewide to enable similar planning exercises to be conducted.

As a consequence of the Commission's lead, other agencies and private companies are seeking GIS advice, assistance and data from the Commission.

The use of the GIS by the Commission was recognised by the awarding of the 1988 Australian Government Technology and Productivity Gold Award.

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GIS'90 Symposium

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The Global Forest Inventory: Measurements using Satellite Imagery and Geographic Information Systems in Amazonian Forests

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Extended Abstract

Forests are secondary only to the oceans as an earthly force influencing climate and the human habitat. The area of forests globally has declined almost continuously with the expansion of the human population. The destruction continues with the present surge in human numbers. The effects are measured in the accelerated accumulation of carbon dioxide and methane in the atmosphere, the rapid loss of species from once-rich terrestrial habitats, in the accelerated impoverishment of large areas cleared of forests but incapable of supporting sustained agriculture, and in changes in the abundance and quality of water in streams. These transitions are currently common in the tropics, but are also occurring in the middle and higher latitudes of both hemispheres as human influences continue to spread.

Contemporary data defining the dimensions of forests, especially their distribution and area, changes in area, their stature, productivity, and carbon content are now clearly fundamental to appraisals of both the causes and effects of the warming of the earth, to efforts at protecting the diversity of life, and to regional and, now global, efforts at stabilizing climate.

We have explored techniques for using satellite imagery with geographic information systems for appraising changes in the area of forests in both temperate and tropical zones. The higher resolution satellite data such as TM and SPOT can be used with high fidelity to recognize and distinguish forest and non-forest, usually without visiting the site on the ground. The low resolution data such as those from NOAA AVHRR LAC offer much uncertainty in this classification. Where this classification has been established with accuracy, estimates of deforestation are commonly exaggerated.

The compromise between economy and accuracy argues for a combination of the higher and lower resolution imagery in a sampling system. Such as system is being applied in the Amazon Basin.

The importance of such data in the evolution of international management of the biosphere is difficult to exaggerate. One of the most constructive steps that the US might take at the moment would be to make imagery from these satellites available cheaply around the world and to encourage use of the imagery not only in appraising the current status of forests but also the patterns of land use. Such data are now potentially available globally and are fundamental to the challenge of managing the global commons of air, water and land.

Global Perspectives

Session E5
Global Perspectives - 2

The Ecological Consequences of Land Use Change

GIS for Sustainable Development in the Nordic Countries - Case Studies from Norway

The Lands System - A Land Analysis and Decision Support System

GIS'90 Symposium

Vancouver, British Columbia
March 1990

The Ecological Consequences of Land Use Change

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Abstract
One of the functions of the Institute of Terrestrial Ecology (ITE) as a research institute within the Natural Environment Research Council (NERC) is to define the effects of changes in land use on ecology and the environment within the United Kingdom (UK). An essential part of ITE's role is to assess the implications of past, present and future national and international policies on the terrestrial environment. Information about the consequences of land use change is required by many organizations including all types of land user, government agencies and parliamentary committees. As the results of ITE's studies are sometimes required to be applied at a national level, there is an obvious need for a system which can manipulate and present ecological and environmental information in a geographical format. The solution currently being employed is the use of a stratification of 1 km squares which allows surveyed information to be collected in detail and analysed at national and regional levels.

Introduction

Much of the information which is required to assess the consequences of policy change on the environment is impossible to census completely at a national level. So, in 1975, ITE established a classification of land in Great Britain (GB) as a basis for stratified sampling for a national survey of vegetation and land use. The system has been used in many subsequent national and regional studies, including ecological surveys of GB in 1978 and 1984; it is proposed to carry out a re-survey in 1990. There are several benefits in the application of a stratification to surveys, especially if the features of interest are correlated to the variables upon which the classification is based.

The aim of this document is to review the ITE approach describing the classification, its application and analysis using Geographical Information Systems (GIS). The paper is divided into 3 sections,

i. the ITE Merlewood Land Classification,
ii. field survey,
iii. manipulation and analysis involving GIS

i. The ITE Merlewood Land Classification

The decisions taken during the creation of the land classification were made during the mid-1970s prior to the major expansion in the use of multivariate classification techniques, and at a time when computers were less powerful than now. It is therefore useful to provide the historical summary of the context in which decisions were made so that their consequences can be fully understood.

The requirement in 1975 was to provide information on the distribution and total area of main vegetation types and land uses. Complete census of most UK environmental parameters was not possible then and is still not practical today. ITE recognized the need for a system which could provide a description of the land types in GB as a sampling framework for field survey. The system needed to reconcile the requirements for detailed ecological assessment, within the limits of resources for survey. The system had to be flexible, handle a range of ecological parameters, produce statistics at national and regional levels and, above all, be objective.

It became clear that a sampling strategy would have to be devised. The approach adopted was analogous to that used in the production of opinion polls, in which the population is divided into predetermined social strata from which samples are drawn. The strata, in the present situation, were defined by environmental characteristics and were subsequently sampled for a variety of ecological purposes. The techniques had been developed and tested in regional studies in the Lake District (Bunce et al. , 1975) and then more widely in Cumbria (Bunce et al., 1978).

The system of classification and survey was based on the grid defined by the Ordnance Survey with each sample unit being 1 km square. The intention was to provide a convenient base suitable for field survey which was readily referenced by map and consistent over the whole country. There are, therefore, two types of application: first, to provide assistance in deciding where sampling information should be obtained (section ii describes the field survey); and second, to convey information about the probable characteristics of an area which has not been subject to field sampling.

The principle behind the land classification is that the major significant ecological variables are associated with environmental variables (eg, altitude) which can be recorded from existing cartographic sources. A regular sampling grid of 15 km x 15 km was placed over maps of GB and information recorded for each 1 km square which occurred at the intersections of the grid. This produced a systematic sample of 1228 1 km squares. Environmental parameters of 4 types were recorded for each 1 km square.

1. Climate
2. Topography
3. Human geography
4. Geology and drift

The approach was to include as many variables as possible in an attempt to remove bias due to selection, with limitation of availability from existing maps. A total of 47 environmental variables (eg, altitude) were recorded; these were divided into 188 attributes by division into 4 equal categories. A further 93 attributes (eg, geological formations) were also recorded giving a total of 281 attributes overall. The analysis was carried out using Indicator Species Analysis (ISA) (Hill et al., 1975), from which Twinspan has subsequently been developed.

The classification was stopped after 5 levels of division, which produced 32 groups, termed land classes. ISA works first by ordering the records (in this case the 1 km square) according to the attributes present and absent and then dividing them into two groups. Each group is then successively ordered and divided further, the classification method being as polythetic, hierarchical and divisive. The technique identifies the attributes upon which the divisions are based (indicator attributes). The indicator attributes can then be used as a key to identity the land class of any further 1 km square (Barr et al., 1989) with 76 attributes being identified from the initial 281 as indicators of land class. These indicator attributes were then recorded for the 4 x 1 km squares offset by 3 x 1 km squares on the diagonals from the corners of each of the original 1228 x 1 km squares. This provided a further sample of 4800, allowing for those falling in the sea, on an almost even grid of squares. The land class of these squares was then identified using the key. When combined with the initial 1228 1 km squares, a total of 6028 1 km squares been identified by land class, a sample of approximately 1:45 (the deficit being those that fell entirely in the sea) of the 1 km squares in GB (Figure 1). Every 1 km square in GB (approximately 233 000) has been identified to land class using the discriminant analysis on a reduced number of variables. This has produced approximately 45% agreement with the original classification, which is being repeated (using Twinspan) on as near to the original dataset as possible.

The land classes show well-defined geographical distributions which can be interpreted in terms of combinations of

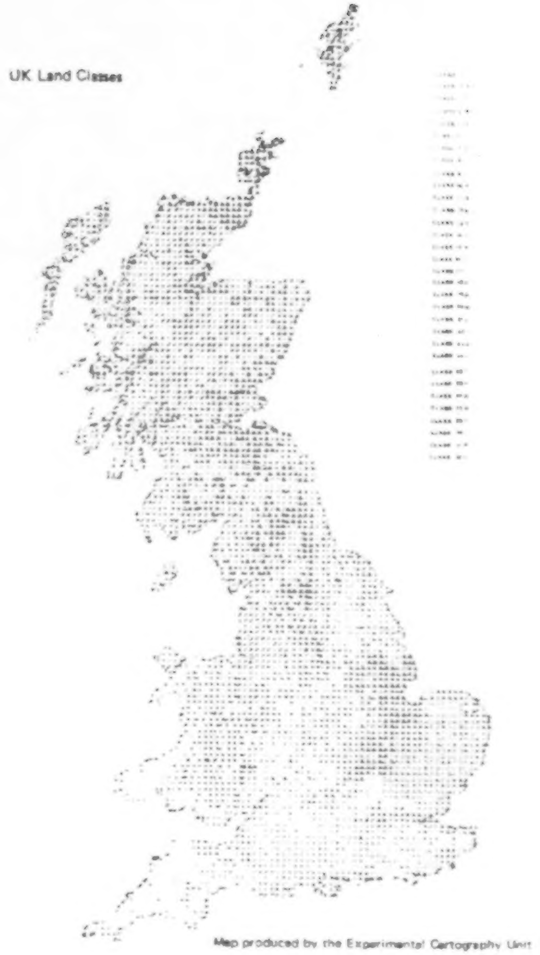

Figure 1
The distribution of land classes for a 1:45 sample of the 1 km squares in Great Britain

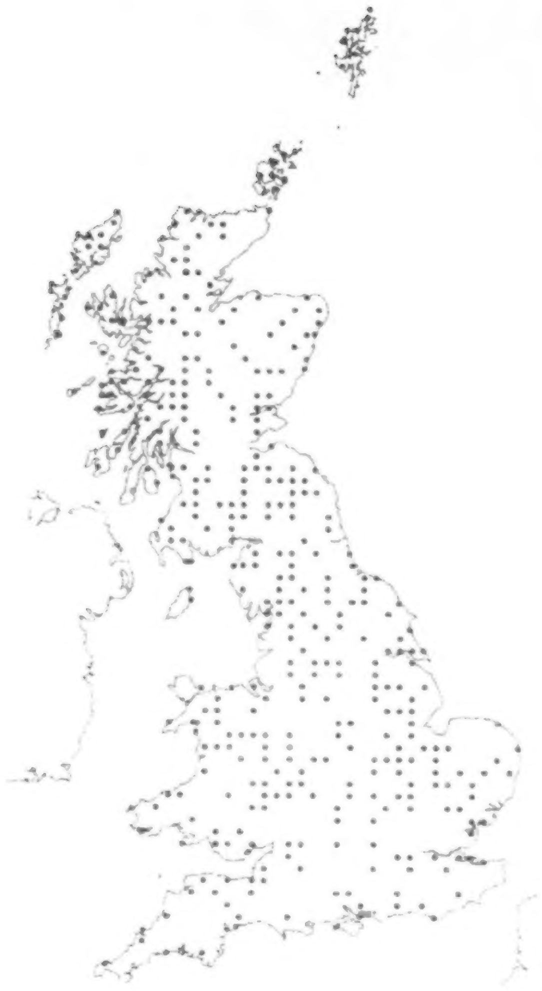

Figure 2
The distribution of 1 km squares surveyed in 1984

environmental features. The initial divisions are dominated by altitude, climate and geographic location (i.e., distance to the south and west coast) but the later divisions are discriminated on a broader spectrum of features (eg, geology and slope).

II. Field Survey

The classification has been used as the basis for 2 major national surveys. In 1978, 8 km x 1 km squares were drawn at random from each of the 32 land classes from the 1228 squares (i.e., a total of 256 squares) of the initial analysis carried out in 1977 (the additional squares were not available until 1979). Each 1 km square was visited and the land use of each parcel and dominant vegetation was recorded. The vegetation was sampled in more detail by sampling with 200 m^2 quadrats and linear quadrats. Information on soil was recorded and sampled at the quadrat sites and livestock types and woodland types recorded. A summary of the land use and land cover information from the 1978 survey is given by Bunce & Heal (1984).

In 1984, the same 256 x 1 km squares were revisited, but the sample size was increased by drawing a further 4 x 1 km squares from each class (i.e., 384 x 1 km squares in total, Figure 2). The aims of the second survey were (1) to detect change from 1978 (2) to improve the characterization of the strata, (3) to collect more detailed information about land use and cover in each square. The quadrat and soil information (items i-iii in the list above) were not repeated. The information was recorded by marking the actual areas, or lengths of linear features on each of 5 maps, namely:

i. Physiography and water.
ii. Agriculture (including dominant plants where the cover was greater than 25%).
iii. Forestry, woodland and isolated trees.
iv. Buildings and human artifacts.
v. Boundary types.

Some of the major changes recorded between the 1978 and 1984 surveys were presented in Barr et al. (1986). Further analyses are in progress.

The field data recorded for each land class is combined together with the cartographic environmental information to provide detailed descriptions of the land classes (Bunce et al., 1981 and Benefield et al., 1982). The 6028 1 km squares classified by land class enabled the estimation of the total number of squares in each land class in the whole of GB. The procedure involves an error term for each class of up to 0.7% of the total number of 1 km squares in GB (233 775). These errors will be removed when the complete coverage of GB is available (Section 3.1). The land class sample mean for a given land cover type is multiplied by the estimated number of squares in order to obtain estimates of land cover types of that land class found in GB. A national total can be produced by summing the areas for each land class. The formulae for error estimation are provided by Cochran, (1968) equations 5.1, 5.10 and 5.11.

It is also possible to predict the amount and distribution for regions within GB, by using the area of each land class within the region, rather than the national totals. Such a procedure is analogous to use of regression relationships to predict other members of a population.

The variables used to create the land classification were those readily available in cartographic form and define the main physical features of GB. Soil type was not included because, firstly, the information was neither even in quality nor available in sufficient detail in 1975 and, secondly, one of the initial objectives was to obtain independent soil data included in the field surveyed information.

Since the production of the classification, more generalized soil information has become available, in particular the soil maps at a scale of 1:250 000. Resources have not been available for the incorporation of the complete digitized soil map into the land class descriptions, but it is hoped that such soil map data will shortly be incorporated in order to improve the definition of the characteristics of the land classes.

The figures published by MAFF and DAFS provide a convenient test of the sampling system and the estimates agree reasonably with them, particularly for crops with large areas. For example, the DAFS/MAFF figure for wheat (1978) was 1.16 x 106 ha, whereas the land classification figure was 1.11 x 106 ha, and for barley were 2.31 x 106 ha and 2.19 x 106 ha respectively. A complete table is given by Bunce et al., (1981). Other published data show similar patterns of comparability with estimates from the land classification. The area of increase urban land was estimated by Best (1976) at 148 km squares/year, whereas a trial study using the classification suggested that it continued at an average rate of 149 km squares/year between 1971 and 1981. A third example results from the MAFF study of improvable land carried out in 1980 in the north of England. Measurements were made of the area of Agricultural Land Classification (ALC) grades 4 and 5 for the entire region during the study and were subsequently repeated using a sample number of squares drawn from the land classification procedure. From the ALC map the proportions of land graded 4 and 5 were 31.0% and 15.6% respectively, and from the land classification 28.1% and 15.7%.
Various types of correlation analyses can be carried out to test the overall links between the environmental classification and the various sets of survey data. For example, the mean value of the first reciprocal averaging ordination axis of the initial environmental data used by ISA to produce the first division in the land classification was calculated for each land class. Principal component analysis was used to extract component values from the matrix provided by the mean values of the areas of the land use in the sample squares from each of the 32 land classes. Similarly, component values were extracted from the mean proportions of each soil group in each of the 32 classes. The correlation coefficients from the mean axis scores from the land classification were 0.823 with the first component of the land use data and 0.923 with the first component of the soils data ($P<0.001$, 30 df in both cases). The procedure followed is comparable with that described by Fourt et al., (1971) and demonstrates the high correlations present between the analysis of map data and subsequent field survey.

III. The Application of GIS Techniques

The data is all identified by 1 km square grid references, but the analysis and presentation are effectively at two resolutions; first, where the 1 km square is the complete domain and second, where GB is described as a raster image composed of 1 km square pixels. Surveyed information has all been digitized and is manipulated in vector form. Initially, the requirement was to produce estimates of areas and lengths of features, which could then be presented as land class means and applied to the national distribution to produce totals for GB. The analysis has been performed on a variety of systems, but now would be done in ARC/INFO or Laser-scan.

We are concerned about the error terms within the process, which we are not currently estimating; these include the accuracy of the original Ordnance Survey map, the accuracy of the field recorder, the accuracy of the digitizing and the accuracy of the different systems upon which the work has been carried out. There is a common belief that census data, expressed without error terms, is totally accurate; it may be that the deviations are negligible but they must be recognized and assessed.

The surveyed squares have also been examined in desk top studies to identify potential changes; for example, the land available for forestry was identified under different economic scenarios by comparing the profitability and suitability of every parcel to different forestry and agricultural managements. The potential for different agriculture is also being modeled using a linear program built around the land classes of Harvey et al. (1986).

More recently we have been investigating the differences in pattern recorded in different land classes. This has involved a number of measurements, ranging from descriptions of populations of parcels (eg, size and perimeter), through measures of relationship of different parcels to position in space. The scale of pattern is being investigated using a two term local quadrat variance method (Hill 1973).

One of the strengths of the ARC/INFO system is that it allows predictions made for individual 1 km squares to be overlaid and predictions of the gross interaction to be made, rather than producing population estimates which will only allow net differences to be assessed. Ecogically, the gross management of the environment may be far more important than the population totals.

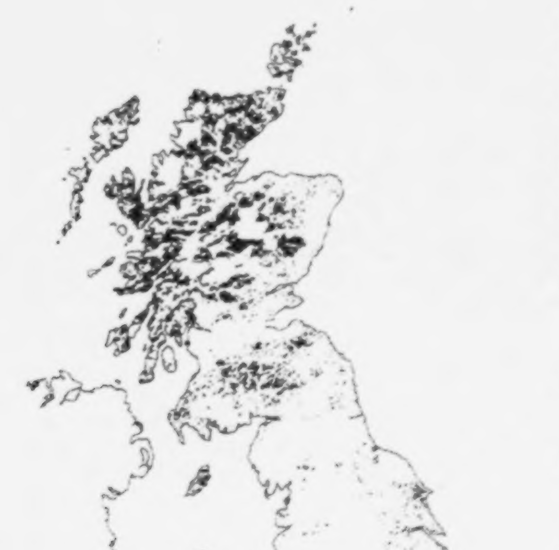

Figure 3
The distribution of 1 km squares which are not constrained for the construction of wind turbines

The other style of data for manipulation is a large raster dataset describing the whole of GB. The data are held as a complete raster in an ORACLE database, although for some variables (such as land class) a quadtree or run length system would be more efficient. Maps are produced using a Grafix system written by NERC Computer Services, which is GKS-based; analyses are produced using a variety of packages including SAS. The information held includes that on which the classification is based and Ordnance Survey data describing towns, villages, woodlands, roads etc.. The information has been combined in a study to identify the potential for wind energy, which identifies unsuitable squares from data such as the human geography and designated constraints (eg National Parks) and overlays the information with the predictions of the mean number of turbines which could be built in each land class. The mean number of turbines was identified by visually assessing the 384 1 km squares, although a software solution would now be possible (Figure 3).

In summary, the classification was produced initially as a structure to direct field surveys. It was designed to be an ecological and environmental classification; accepting that there will be many features for which it is not the optimal solution. One of the main problems the system avoids is the expense of the production of absolute census data and it has the advantage of allowing the sampling error to be assessed. The system has been extended to be used as a modeling framework, allowing both expert opinion and calculated predictions to be applied to Great Britian.

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GIS for Sustainable Development in the Nordic Countries - Case Studies from Norway

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Abstract

There is a strong tradition of mapping for land use planning in the Nordic countries, but use of GIS for sustainable development must be said to be in the starting phase. This application is expected to undergo dramatic development in the 1990's.

Five case studies from Norway are presented. Case A describes development of a GIS with natural resource data for use by agriculturalists, foresters and other professionals over the entire country. Case B discusses cooperation between 6 townships to develop a GIS with environmental data for use in land and developmental analyses in the area. Case C gives examples of use of the GIS in environmental planning in a township and a county. Case D discusses research and development work to combine raster and vector data in mapping and management of vegetation and other land resources. Case E considers image analysis of digitized colour infrared aerial photos to document tree damage in parks and productive forest.

The oral presentation is illustrated with colour slides.

Introduction

There is a long and strong tradition of mapping for land use planning and use of natural resources in the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden). At the end of the 1960's, digital map production methods were introduced and gained increasing importance throughout Scandinavia in the 1970's and 80's. The last few years have witnessed an accelerating growth in the use of geographic information systems (GIS) in physical planning, mapping of natural resources, planning in forestry, and work with other environmental data. It is probable that all of the approximately 1500 townships in Scandinavia will in the course of the 1990's introduce GIS as a tool for increased effectiveness, improved analysis and presentation, and increased public participation in physical planning.

Seen in this perspective, Scandinavia is in the initial phases of using of GIS technology. Even though large national systems are being planned and established, routine use of GIS connected with efforts for a more sustainable development is still very limited, and the activity may often be characterized as developmental work. The first Nordic conference on the use of GIS, held in Norway in November 1989, however, showed that many users are now about to take the step from developmental projects to operative use of GIS. This also applies to applications of direct relevance for sustainable development.

The case studies presented here are chosen somewhat arbitrarily, but should give participants at GIS'90 some insight into the "state of the art" in Norway. The examples are reasonably representative for the rest of Scandinavia as well. The oral presentation is accompanied by colour illustrations slides. For technical reasons, none of these are reproduced in this paper.

Figure 1 shows the geographic location of the case studies presented.

Case A

Geographic Information System for Natural Resource Data at the Norwegian Institute of Land Inventory (NIJOS). Users: Foresters, Agriculturalists and other Professionals Over the Entire Country.

NIJOS is a publically-funded institute operating over the entire country. The Institute's main endeavor over the last 20 years has been the mapping of the natural resource bases for production for agriculture and forestry in Norway. These data are presented on "Economic map of Norway" at original scale 1:5 000. Approximately 200 000 sq. km. are mapped. This corresponds to the presumed productive area under the forest limit, plus some of the area over forest limit. The remaining 124 000 sq. km. of mainland Norway are primarily mountain plateaus and glaciers.

A digital soils register for Norway was begun as early as 1975. This register was not linked to maps, and could only give users standard data printouts sorting the land area information by administrative units, owner and user boundaries of properties, altitude, etc.

NIJOS has now undertaken the development, operation, and maintenance of a GIS for soil, forest and vegetation resources. The strategy is that NIJOS, by building up a GIS for these natural resource data, will encourage multiple use of the data, with distribution primarily by network. In addition to a series of standard graphical and numeric products, NIJOS will also be able to "tailor-make," on order, using a flexible report generator, various user-adapted products. One can consider here, for example, thematic maps that can contribute to better planning aimed at reducing pollution from agriculture. After the "algal catastrophe" in the North Sea in the summer of 1988, this problem has received increasing attention in Scandinavia. As examples, we will look at some of the products this can lead to.

The basis map is the Economic Map. This is supplemented with more detailed data on soil types. A soil type is defined by physical, chemical and climatic criteria, and represents a relatively homogeneous area with respect to the most important environmental factors for plant cultivation, and therefore, also a certain yield potential. At least one soil profile within each type distinguished is described in detail. The soil type map is therefore a very detailed map, presented in the original scale 1:5 000.

For farmers and planners in general, the original material will be difficult to access or unavailable. The data base contains, however, a multitude of possibilities for producing simplified, "management-oriented" thematic maps of, for example, drainage requirements, irrigation requirements, suitability for various cultivars, fertilizer requirements for various cultivars, erosion susceptibility, likelihood of phosphorus runoff, etc.. Figure 2 shows some examples of such products.

Corresponding models will be developed for various kinds of forest use, and existing models for production of derived thematic maps from maps of natural vegetation based on ecology/plant sociology will be adapted to the possibilities offered by GIS. This has the potential to eventually become a very important data base for practical use in planning for a sustainable development.

Case B

Environmental Data Project in the Nidar-group. Users: 6 cooperating townships.

Nidar group is an inter-township association in the Arendal area. Six townships cooperate through it to resolve social issues where there is agreement that the boundaries of each township give a too-restrictive geographical framework for resolution of the problem. The Environmental Data Project is one such cooperative task. Participants include, in addition to the Nidar group, the Geodatasenter in Arendal, the County Mapping Authority in Aust-Agder, VIAK a/s, and the County Environmental Protection Office of Aust-Agder. As in Case C, the project is part of a comprehensive national program to strengthen environmental protection work at the township level.

Nidar group has decided to prepare a land and development analysis to clarify and prioritize land uses for the near future. This is necessary because of increasing land pressure and resulting conflicts regarding land use.

The base map and contents of the plan are established in a GIS at the Geodatasenter. Nidar group uses digital base maps with water contours, road net, and administrative boundaries. Environmental data are extracted from plan documents in the six townships and adapted for coordinated analysis and presentation. Necessary supplemental environmental data are entered in the property database for use in the analysis work.

On the basis of digital map information and associated property databases, various thematic maps, graphics and statistics are produced for use during the planning process and for public information and participation.

All data compiled in the Environmental Data Project are immediately available for viewing on a terminal or as plotter printouts through menus in the information system. Using ARCINFO, portions of the data contents can be sorted and presented by desired parameters.

Nidar group's conclusions after completion of the pilot stage of the project are:

1. GIS methodology is regarded as clearly superior to the former, more traditional working methods using analog maps and EDB registers. Some of the reasons for this are:
   - Plan changes can be visualized immediately,
   - Maps and graphics/statistics for use during the planning process can be produced in small numbers at a very competitive price,
   - "Management-related" thematic maps can easily be derived, for example, bus routes/recreational areas, habitation/containers for glass recycling, bathing areas/bathing water quality, sewage network/placement of unconnected buildings, etc.

2. The project has also shown that more work is needed is some areas, for example:
   - Ownership rights to data,
   - Maintenance routines,
   - Classification of sensitive data (limited access),
   - Spread of unauthorized data.

Figure 3 shows examples of material from Nidar group's GIS.

Case C
Use of GIS in Planning at the Township and County Level in Vestfold County.

1) Adaption and presentation of thematic maps for township plans in Nøtterøy township, Vestfold.
Nøtterøy township is part of the pilot project for development of maps and geodata relevant to environmental planning in townships. In connection with this project, the County Mapping Authority in Vestfold made map databases of areas that were protected or warrant protection, (recreational areas, etc.). The Institute for Environmental Analysis had previously made a digital-based map of wildlife regions for the entire county, and the Nøtterøy portion of this was used. All maps were digitized from manuscripts at a scale of 1:10 000. During the digitization, good possibilities for thematic separation and coupling to register data were incorporated. The map material is processed in ARCINFO and can be presented as plotter printouts or colour scans for printing in larger numbers. Figure 4 shows examples of thematic maps produced for use as posters with information about the work in Nøtterøy, and at a smaller scale, as maps appended to the land use portion of the township plan.

According to the environmental protection consultant in Nøtterøy township, the map material has had an important function in the planning process with regard to public information and participation. Work is now underway for the township itself to install programs to use GIS in planning.

2) Evaluation of the coastal area in Vestfold county with regard to raising fish and shellfish.
The LENKA project covers the entire Norwegian coast, and aims to give a better basis for correct use of resources in this important zone. A wide range of data are mapped, including appropriate use of the areas, release of waste water and other forms of pollution, existing protected areas, etc. Digital maps with coupled property databases have been prepared. The material is used both for public information and as a basis for evaluating applications for permits to establish new fish farms. Figure 5 shows examples of cartographic presentation of some of the information.

Case D
Combination of Raster and Vector Data in Mapping Vegetation and Land use in Aust-Agder and Telemark Counties.

Satellite images from Landsat 5 Thematic Mapper and from SPOT were used in several subprojects for the purpose of mapping vegetation and land use. The work has focused on clarifying what level of detail is possible, given the Norwegian landscape conditions, and in what degree satellite data can supplement mapping based on aerial photography and/or field studies.

The projects were carried out by the Telemark Research Foundation, the Centre for GIS And Remote Sensing a/s and VIAK a/s in cooperation. Base funding was through the Royal Norwegian Council for Scientific and Industrial Research. The Forestry Association of 1950, the Norwegian Forest Owner's Association, and Bykle and Valle townships have contributed financially. The State Mapping Authority has provided the project with base maps.

As mentioned under Case A, detailed data on the resource base for production in agriculture and forestry exist in the Economic Maps of Norway. In addition, an even more detailed forest survey for planning and management purposes is being carried out by two forest-owner associations, both in large forest properties and by townships in areas having many smaller forest holdings. This mapping is conducted using detailed field work supported by aerial photo-interpretation.

It is improbable that satellite data with a pixel size corresponding to a minimum ground area of 30 x 30 m (TM data), 20 m x 20 m (SPOT) or 10 m x 10 m (SPOT panchromatic data) can replace large-scale aerial photography as the basis for studies at the level of detail desired. But satellite data has the advantage of simultaneous coverage of relatively large areas, and can among other things,be used for mapping changes in land use and to give an overview of the main features in distribution of vegetation types and other areal categories. In addition, it provides the possibility of mapping Norway's large mountain areas, that for the most part are only covered by topographic maps at a scale of 1:50 000 or less.

All satellite data are first precision-corrected, that is, made to correspond to existing maps within defined limits of deviation. This allows coupling of the satellite image to topographic base maps or other vector-based information.

Two main types of image analysis are then used: colour-coding with HLS-transformation for visual interpretation, and the so-called cluster technique. Briefly, colour-coding with HLS entails using an algorithm describing colour as hue (H), light intensity (L) and saturation (S) to present the registered spectral signature as a colour image, instead of using the common RGB coding (red, green, blue). This gives improved possibilities for colour coding suitable for visual interpretation.

In clustering, the spectral signatures clustering around a given value are assigned to that value. Each cluster can then be presented with a given colour, preferably such that there is a logical connection between the colours and related vegetation and land area types.

1) The Hovden area was used as a test region for visual interpretation of colour-coded satellite images, partly because we had available a detailed map of vegetation by plant sociological criteria covering an approximately 30 sq. km. area. Boundaries and type codes from this mapping were digitized and processed using ARCINFO, and a property batabase with supplementary information about each polygon (each separated areal unit) on the map. We can enter additional information into the property database using dBASE. The digital map and property database provide the basis for producing a number of derived maps, for example, simplified map overviews of main vegetation features, nutrient relations, water source, duration of snow cover, etc., or corresponding statistics, diagrams, etc. These thematic maps have been used to document areas warranting protection in a nature reserve and parts of a protected landscape region in Hovden. The Environmental Protection Office in Aust-Agder commissioned the mapping.

Information from satellite images can be processed using the image analysis program ERDAS, which is compatible with ARCINFO, and thereafter combined (using ARCINFO) with detailed vegetation maps, maps derived from these, etc. We expect that such combinations of raster and vector data will open possibilities for analysis, for example, of variations in the spectral signature of the satellite image and details in the vegetation cover. It also gives new possibilities for presentation of raster - and vector-based data.

Figure 6 shows a photographic combination of vector and raster data. A detailed plant-sociological vegetation map was combined with a precision-corrected, colour-coded section of a SPOT scene. Spectral signatures from land surfaces having certain physiognomic features in common are closely related. An interpreter doing a visual interpretation of a colour-codad satellite image will, therefore, perceive these as belonging to the same area type. This research shows what the various units that can be visually separated may include, and we can evaluate whether the degree of separation attained is satisfactory for a given application or mapping task.

2) Further research with precision-corrected satellite data has been carried out using the cluster technique. The test area here is a valley in Valle township, at an elevation of 250-1300 m o.s.l.. Figure 7 shows a combination of Economic Map 1:20 000 in scale and satellite data. Even though this technique can't compete with the precision that detailed field work and aerial photography gives, it is in our opinion, a useful tool for small-scale mapping and the calculation of areas of the various categories. This method will be particularly appropriate in areas lacking detailed land resource maps.

Case E
Image Analysis of Digitized Colour-Infrared Aerial Photos for Analysis of Tree Damage.

The trials were carried out in a test area in Porsgrunn town in Telemark, near Norsk Hydro's industrial area. The Porsgrunn Park Authority has contributed its time to the project. Norsk Hydro Research Center has contributed financially.

Aerial photos on colour-infrared film at an original scale of 1:7 500 and 1:50 000 were digitized using a colour scanner and analyzed by the same methods as the satellite images. The scanner resolution and original scales used gave pixel sizes corresponding to ground quadrats measuring 40 cm x 40 cm and 2.5 m x 2.5 m, respectively.

Good results have been achieved in identifying the state of vitality in trees using digitized aerial photos with 40 cm x 40 cm pixel size (Figure 8). At a pixel size of 2.5 m x 2.5 m, it is not possible to identify smaller trees, but the main features with respect to vitality can still be observed. A practical limit for reliable identification of individual trees is considered to be a pixel size of about 1 m x 1 m for Norway. Until such time as imaging spectrometry becomes a fully operative technique, we would consider the method described to be a relevant remote analysis method for practical mapping of vitality in parks or in permanent control plots in productive forests. Since aerial photos can often be used for several purposes in the study area, the cost of this kind of remote analysis can be affordable.

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The LANDS System - A Land Analysis and Decision Support System

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Abstract
This paper presents a GIS-based Land ANalyis and Decision Support (LANDS) system. The LANDS system integrates GIS applications with relational data base management (RDBM), mathematical programming, and expert systems applications. The paper describes the programs and procedures used to construct a mathematical program to match crop systems to land types. The resulting land use plan maximizes net farm income for the region. The LANDS system uses the GIS module to define land management units (LMUs). These areas are homogeneous in biophysical, land use, and economic characteristics. The LANDS system uses the RDBM module to create a mathematical programming model to allocate LMUs to crop systems. The GIS displays the results of the land allocation model.

1 Introduction

This paper describes a regional Land ANalysis and Decision Support (LANDS) system developed in cooperation with the Malaysia Department of Agriculture. The system uses a land allocation model to identify patterns of land use which return the highest regional net farm income. It does so within the controls of policy and limited resources such as land and labour. Land use options include growing crops on different rotations. They also include different methods of growing the crops. The system assigns limited resources to user specified land use options. The land analysis and decision support system displays the proposed distribution graphically, as maps, and in report tables.

1.1 The LANDS Shell

The LANDS system uses a set of custom and commercial programs called the LANDS shell. The LANDS shell provides geographic data analysis and manages the biophysical, economic, resource, and production data. It also produces crop budgets, generates the computer code to run the optimization model, and reports model results. Land evaluation specialists use the shell to build and run the land analysis and decision support models.

1.2 Land Analysis and Decision Support Definition

Land evaluation is a widely used term. Some uses restrict the meaning to the interpretation of biophysical properties for forest or agriculture capability or crop suitability. In some cases, evaluation procedures use simple economic analysis (e.g., benefit-cost analysis) to rate feasibility. The procedures described in this paper integrate economic with biophysical analysis to assign crop systems to land. They optimize the use of available resources. The LANDS system assists with or supports land use decisions. It does not make land use decisions. The term land analysis and decision support emphasises this role. The following procedures define the LANDS system.

1. Define the management goals.
2. Define the options for meeting these goals.
3. Define the resources available to meet the goals.
4. Define a land allocation model to meet the management goals.
5. Execute the allocation model.

2 The LANDS Shell

The LANDS shell consists of several commercial and custom designed computer programs. A custom program provides a menu system to access the various components of the shell. Other programs perform budget analysis, build models and process and transfer data between applications. They also produce reports and provide input for the production of maps. Another set of programs convert geographic data from an unsupported geographic information system to the LANDS system GIS. The commercial programs manage data (Oracle[1]), perform geographic analysis (TerraSoft[2]), and solve optimization problems (LINDO[3]). Figure 1 displays the structure of the shell.

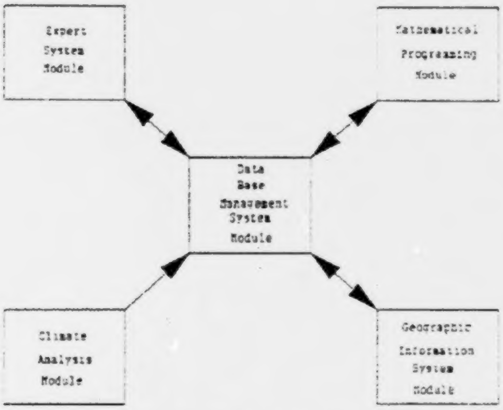

Figure 1. The LANDS Shell

2.1 Geographic Information System

The geographic information system (GIS) stores, edits, analyses, and retrieves geographical data as maps. In addition to providing digital storage and retrieval of map data, the GIS provides the following functions.

1) calculation and storage of data on areas, locations, and topology of classes of land.
2) overlay of map themes to produce composite themes.
3) evaluation of data attached to polygons and development of interpretations from these data.
4) plotting of interpretations as maps.

2.2 Data Base Management System Module

The data base management system (DBMS) inputs, stores, edits, updates, and retrieves data. The data base is designed to store data in only one place. All models or programs which use the data automatically reflect any changes made to the data. The DBMS applications retrieve and analyze data. These applications provide data to the expert system, produce crop budgets, and build the land allocation model. They also link land allocation model results to the GIS for display.

2.2.1 Budget Application

The budget application is a set of custom programs written and run from within the DBMS. It calculates input costs, production revenues, and annual net farm income for each land use option. Other applications use these values.

2.2.2 Mathematical Programming System (MPS) Application

The MPS application is a set of custom programs built and executed from within the DBMS. It processes information supplied by the DBMS and builds the land allocation model. The application retrieves the data which define the land use options, resources, and limitations to production. It also calculates and formats the input data for the land allocation model.

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[1] Oracle Corporation, Oracle RDBMS. 20 Davis Drive, Belmont, CA 94002-9806

[2] LINDO Systems Inc., LINDO, Linear Discrete Optimizer. P.O. Box 148231, Chicago, Illinois 601614

[3] Digital Resource Systems Ltd., TerraSoft: Geographic Information System,. 402-495 Dunsmuir St., Nanaimo, B.C. Canada, V9R 2V2

2.2.3 Report Application

The report application presents the results of the land allocation model. Reports include summaries of crop areas and production, resource requirements, and annual net farm income. Changing input to the land allocation model provides a method of sensitivity analysis.

2.3 Mathematical Programming Module.

The mathematical programming module performs part of the economic analysis required by the LANDS system. It maximizes or minimizes an objective function subject to defined limits or constraints. The mathematical programming module solves the land allocation model to maximize regional net farm income.

2.4 Expert System Module

The expert system module (AgriExpert[4]) is a custom program designed to match two sets of resources. It uses an 'inference engine' which compares the properties of two sets of resources. One application is the determination of soil suitability for crops. The inference engine compares the range of properties of each soil with the requirements of each crop. If the range of soil properties required by the crop encompasses the range of properties in the soil, the soil is suited to the crop. If the range of soil properties required by the crop does not overlap the range found in the soils, the soil is not suited to the crop. If the ranges partially overlap, the program identifies the conditions where the soil and crop match.

2.5 Climate Analysis Module

These custom programs analyze daily records of rainfall and potential evapotranspiration, based on pan evaporation and crop use factors. It calculates the chance that each ten day period will be too wet or too dry. The program then produces a distribution of soil water condition, by 10 day period, for each climate station analyzed.

3 LANDS System Procedures

3.1 Management goals.

The land allocation model of the LANDS System uses mathematical programming to assign areas to each land use option. This requires a goal which can be stated in mathematical terms as an objective function. Our current model maximizes net farm income.

3.2 Land Use Options

A land use option is a set of conversion, improvement, and crop system operations practised on a type of land. Some land use options may not require improvements. Defining land use options requires defining Land Management Units (LMUs) and conversion, improvement and crop system operations.

3.2.1 Land Management Units

A land management unit (LMU) is a class of land which is relatively homogeneous in its biophysical, land use, and economic properties. Definition of LMUs requires the combination of all three themes. The following sections describe the sequence.

3.2.1.1 Crop Management Units

The crop management unit (CMU) is the biophysial component of the LMU. The CMU incorporates the climate, soil, and terrain properties which define biophysical crop suitability. Regional climate and microclimate dictate the range of crops and maximum production potentials of an area. Climate is not normally subject to management, although microclimatic limitations can be modified. Soil and terrain conditions impose further limits to crop suitability. Some of these limitations are manageable, others are not. Crop management units are defined in 4 stages.

Stage 1 defines the biophysical crop requirements. Matching improvement and crop system operations to land requires information on the biophysical requirements of the crops under consideration. These requirements are the basis for setting up land classes which can support the same range of crop systems. The crop specialist is responsible for providing class limits which define suitable soil, terrain, and climate conditions for each crop.

Stage 2 defines agroclimatic areas. Climate defines the range of crops which will grow in the area. Custom programs within the LANDS shell analyze climate station data to determine climatic conditions related to crop growth. Climate classes determined at each station provide the data to produce agroclimatic maps. These maps are drawn manually and digitized for use in the geographic information system.

Stage 3 overlays the climate areas defined in stage 2 with the soil and terrain maps for the study area. The resultant polygons carry the biophysical attributes used to determine crop suitability.

Stage 4 defines land units which have the same kind and degree of limitations to crop production. Soil and terrain conditions restrict suitable cropping systems. They also dictate the land improvement operations required to produce specific crops or crop mixes. The land area must be classified to form units having the same suitable improvement and crop production systems and the same expected crop responses.

3.2.1.2 Land Use Classes

Existing land use and cover determine the operations and costs of establishing a proposed land use. The existing land use maps provide area summaries of existing land use. Generalized land use classes are based on the type of cover as it relates to clearing and land preparation costs. Example classes are tree and shrub cover (e.g., secondary jungle or coconut-coffee plantations) and shrub cover (e.g., tea or coffee plantations or abandoned land). Perennial crops keep their original land use class because the land allocation model uses the area and age of existing perennial crops.

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[4] Glen Cooper and Associates, AgriExpert. 510-1190 Melville, Vancouver, Canada, V6E 3W1

3.2.1.3 Economic Zones

In general, unit costs of production decrease with increasing intensity of agricultural land use and transportation efficiency. They increase with distance to market or supplies. The Department of Agriculture's Agriculture Information System uses administrative districts to record commodity and resource price data. The project uses these units as a first approximation of economic zones. Subdivisions of these units, based on intensity of use and transport distances, will define economic zones in the future.

Overlaying maps of CMUs, land use classes, and economic zones delineate polygons carrying attributes of each theme. Each unique combination of CMU, land use class, and economic zone defines a Land Management Unit.

3.2.2 Operations and Commodities

The LANDS system requires data on all operations for the land use options in the planning area. The required data are the type of operation and the quantity and type of commodities associated with the operation. Commodities are resources and crop products. Operations include land conversion, land improvement, and crop system activities.

The following kinds of operations may be required by a land use option. These operations occur within a given year of the crop's rotation.

a. Land Conversion Operations: Existing land use influences the establishment of a crop system. Conversion operations are the operations necessary to convert existing land use to the proposed crop system.
b. Land Improvement Operations: Soil and terrain conditions may prevent the growth of climatically suitable crops. Land improvement operations are the operations necessary to remove these limitations. Some land use options may not require land improvement.
c. Crop System Operations: A crop system is a unique set of operations, along with the resources required to produce a crop or mix of crops. Crop systems include mono cropping, double cropping, intercropping, and crop rotations.

3.2.3 Defining Land Use Options

The combination of conversion, improvement, and crop system operations with a land class defines a land use option. The MPS application of the LANDS system defines the land use options. It links land improvement and crop system operations to the CMU component of the LMU, using a table of crop systems suited to each CMU. The expert system module can construct the table from data in the data base. The MPS application also links conversion operations to the land use component of the LMU.

3.2.3.1 Yields

The LANDS system requires estimated yields for each land use option. The crop system carries an estimated yield. The combination of crop management unit and crop system has a yield factor attached to it. During any yield calculation, the yield factor attached to the CMU modifies the yield attached to the crop system.

3.2.4 Available Resources.

Certain resources may limit the area assigned to a land use option. Limited resources may also limit the total area of land which can be used. The LANDS system therefore requires data on the kind and quantity of any resources which may limit land use options. Land is a resource along with capital, labour, equipment, chemicals, etc. Land resources are discussed separately because of the method used to determine available land.

3.2.4.1 Land resources

All land uses or biophysical conditions which prevent agriculture as an option reduce the area of land available. The GIS overlays land reserves, zoned non-agriculture, etc., on crop management units. It then extracts for analysis only that land which is available for agriculture. The system reports the area of each LMU which is available for agriculture.

3.2.4.2 Other resources

Data for other potentially limiting resources come from questionnaires, surveys, and government sources. Most of this information comes from the Malaysia Department of Agriculture's Agriculture Information System. The DBMS manages this data.

3.3 Crop Budgets.

The budget application calculates annual cash flows for land use options. Crop budgets require data on prices and quantities of commodities for each year of a crop rotation.

3.4 Land Allocation Model.

The land allocation model identifies patterns of land use which return the highest regional net farm income. It does so within the limitations of policy and available resources. The MPS application produces the code necessary to solve the land allocation problem. All the necessary data come from the data base. The application calculates all needed coefficients. The coefficients include discounted net farm income, resource requirements, and yields. The following sections describe the major components of the model.

3.4.1 Time Frame

The model distributes resources and activities across periods. The current model uses a 5 year planning period. Each year is a period. The number of periods is adjustable. The MPS application needs to know the number of periods to construct the land allocation model.

3.4.2 Activities

1) *Opening stock* defines the area of land already in perennial crops. Land in perennial crops is not available for conversion to alternative crops until the end of the crop rotation. The model requires the definition of age classes for perennial crops. The age classes define resource requirements and the times at which land conversion to alternative crops can occur.

2) *Planting activities* are unique combinations of conversion, improvement, and crop system operations, on given land classes (land use options), for a given period. The land

allocation model requires data about which crop systems are possible on which land classes. Crop management units define the possible combinations.

3.4.3 Constraints

1) *Land constraints* impose limits on the area of land assigned to planting activities. The area of land, assigned from a given class, cannot exceed the total area of land in that class. The model requires data on the total area of land in each class.

2) *Opening stock constraints* make sure that land under perennial crops remains under that crop until the end of the crop rotation. The model requires data on the area of land in perennial crops and the age of the existing crop.

3) *Resource constraints* make sure that resource use does not exceed resource availability. The model requires the total of each potentially limiting resource.

4) *Policy constraints* make sure that the land allocation solution meets government production quotas or targets. Policy requirements may impose resource allocations that reduce the net farm income.

3.4.4 Activity Interactions

Activities are dependent on each other because they may compete for the same resources. Also, the choice of certain activities may explicitly require or exclude the choice of other activities. Coefficients entered into the rows of the land allocation matrix define the nature of these interactions.

1) The objective function defines the possible activities and their relative contributions towards the objective. This requires the specification of each activity's coefficient. The coefficient for each planting activity is the present value of net farm income corrected to compare crops of different rotation ages.

2) Constraints define the limitations to production. Coefficients, in the appropriate rows, define these interactions.

3.5 Reports and Maps

The LANDS system can produce an annual cash flow and discounted net present value for each planting activity. It can also produce maps and tabular reports of the proposed land use for each year of the planning period. An important capability of the LANDS system is its ability to perform sensitivity analysis. The land allocation model output provides information on the costs of forcing a planting activity into or out of the plan. This output can also show the sensitivity of the land use recommendations to changes in the net farm income of a given activity. In addition, the LANDS system provides a valuable "what if" tool to assess the effect of price, yield, or policy changes.

4 Conclusions

The LANDS system provides an effective tool to assist with regional land use planning. Output from the system is useful to guide land use decisions. It is useful for assessing the impact of policy or guiding land use changes to meet production goals. The system uses generalized land data and should not be used for site specific crop allocations. An important application of the system is the performance sensitivity analysis and "what if" planning. The primary limitation of the system is the number of activities which the land allocation model can evaluate. The current limitation is approximately 15 000 activities. This is not enough to evaluate individual map delineations for a large map. The next stage of the project is a developing a farm level application that will provide site specific land use plans. We will enhance the capability the system to deal with different types of objective functions, constraints, and activities.

5 Acknowledgements

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Data Issues and Remote Sensing

Session F1
Data Issues in Remote Sensing

Remote Sensing - A Foundation for Integrated Resource Management Information Systems
Ross Rose, MacDonald Dettwiler and Associates Limited

Sustainable Development in GIS as a component in Statewide Decision Support Systems
G. Robinson Barker, SPOT Image Corporation

Remotely Sensed Data: Sensors, Coverage, Data Availability and Access, Cost
Jean Game, Canada Centre for Remote Sensing

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Remote Sensing - A Foundation for Integrated Resource Management Information Systems

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Abstract
Over the past two decades, digital remotely-sensed data has evolved from a largely experimental data source to an integral input into the resource management decision-making process. Information provided by remotely-sensed data now permits timely, accurate and consistent decision making in a cost-effective manner for many operational resource management organizations around the world.

This paper will discuss airborne- and satellite-based digital remote sensing technology and its role as a data source for integrated resource management information systems.

Background

Canada, and in particular Western Canada, bases much of its economic well-being on the export of natural resources. In fact, Canada's largest export industry revolves around the forest sector. The management of Canada's natural resource base is now becoming increasingly complex owing to such issues as integrated land use, environmental concerns and sustainable development. In addition, the public is now demanding a much more active role in the management of these resources.

All of these issues point to the need to provide those charged with managing a resource base with a fully integrated, pro-active decision support capability. The concept of the Integrated Resource Information Management System (IRIMS) is one that has evolved chiefly as a result of this need.

The IRIMS represents an integrated systems solution to operational resource management requirements. It comprises a hierarchical structure consisting of people, information, tools, procedures and communications. This hierarchical structure addresses the requirements for decision makers at all levels within the operational organizations that are involved in resource management, from the definition of policy and associated strategy to the execution of the resulting procedure.

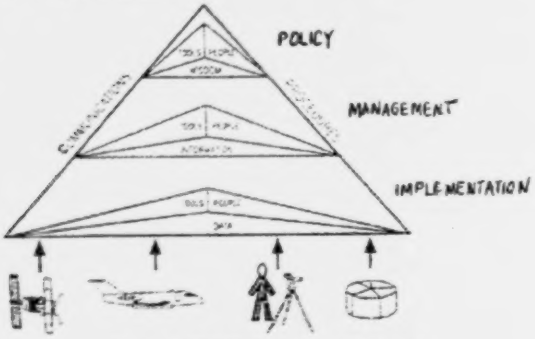

Figure 1 IRIMS Conceptual Diagram

Although the concept of the IRIMS is not new (Baskerville, Moore), the development of such systems has only recently become possible. Advances in digital processing, software, communications and storage technology have provided a basis for the development of sophisticated, integrated systems designed specifically to meet the needs of a particular organization.

The major factor behind the development of the IRIMS is the increasing availability of operationally usable data, in particular, remotely-sensed imagery. As shown in Figure 1, raw data inputs into the IRIMS are received from spaceborne, aerial, ground and existing data base sources. In particular, remotely-sensed imagery provides a regular source of accurate information in a timely and cost-effective manner. As this paper points out, it is the operational availability of remotely-sensed data that provides the foundation for the IRIMS.

This paper explores the remotely-sensed data sources that are, or will be, available on an operational basis for resource management applications in the foreseeable future and will highlight two applications implementations.

Survey of Remotely Sensed Data

Traditionally, the remotely-sensed data used in resource management has been based on cameras which record the energy variations on photographic film. However, photographs are an inherently inflexible media, which require time consuming, subjective operator-intensive analysis, interpretation and correction.

Although digital remote sensing data has been available since the launch of the first Landsat satellite in 1972, the cost-efficient application of this data to the increasing requirements for efficient resource management has been hampered by several factors. Paramount amongst these were the unreliability of the digital data source, and the difficulty in extracting accurate information from this digital data.

In the last few years, technology has advanced to a point whereby the remotely-sensed data can be thought of as quantitative measurements, and objective analysis is now being operationally performed by many resource management organizations. Passive and active digital imagery and digitized photographs provide a variety of sources for the data, which permits objective resource planning and management. Objective quantitative analysis of these measurement sets provides for an accurate and unbiased information source.

There are several characteristics of these measurements that ensure that this remotely-sensed data can be used to support consistent decision-making:

- the digital nature of the data,
- the multispectral component,
- the accuracy of the data,
- the timeliness of the data availability, and
- a secure data source.

A Digital Data Source

The quantization of reflected energy into digital measurements permits computer processing. This is much quicker than photographic interpretation, and is less dependant on the analytical skills of the interpreter. It is therefore a less biased data source. Moreover, the increasing power and sophistication of digital processing means that information can be accessed by users who are not required to be computer experts, but instead be applications experts.

A Multispectral Data Source

The ability to identify and measure different features on the earth's surface based on variations in intensity of recorded energy is greatly enhanced when using sensors that operate over a wide range of the electromagnetic spectrum. Multispectral imagery is multiple simultaneously-recorded images, inherently registered to the same coordinate system, each covering a separate range of spectral wavelengths.

The sensors on existing and planned satellite and airborne systems are sensitive over far greater ranges of the spectrum than aerial photography. In particular, the short wave infrared bands of the Landsat Thematic Mapper have proven to be indispensable to many resource managers actively using remotely- sensed data. Table 1 illustrates the wavelengths in which the Landsat satellite records and describes the features which they have been designed to identify.

An Accurate Information Source

Techniques for geometrically correcting the satellite data have been refined to easily address recognised mapping standards. As well, advanced digital processing systems make this a quick and highly automated process.

Indeed, the geometric correction of imagery to standard map projections, or Geocoding, as it is termed, has proven to be highly accurate. Therefore, this data provides an ideal source for geographic information systems. Satellite imagery also provides wide area coverage and is therefore extremely cost- effective on a per unit/area basis.

Having a cost effective, accurate digital data source means it is possible to combine and compare images from different dates and sensors and to obtain derived information.

Timeliness

Satellite sensors are an ideal data source for resource management because they provide regular and repeated coverage. For instance, Landsat permits complete coverage of the earth every 16 days, while SPOT permits 26-day repeat radar coverage. However, because SPOT can alter the viewing angle of its sensors, there is the potential to revisit any area every 3 or 4 days at Canadian latitudes.

Where higher resolution or more frequent coverage is required, airborne sensors can supplement the spaceborne data. The other key benefit is the digital nature of the data. Such data can rapidly be processed into information and formatted for the particular user, (i.e., maps, reports, statistics, GIS data).

Availability - A Secure Data Source

In the last few years, the availability of this data has become far more secure, with the U.S. Landsat and French SPOT programs creating an operational demand for their products. Recently the Japanese, Indians and Russians have all entered the civilian remote sensing marketplace.

The 1990's will see something of an explosion in the launching of remote sensing satellites. Table 2 illustrates the key characteristics of the satellites to be launched over the next five years. For the next few years, it is the optical sensors such as the Landsat TM and SPOT HRV that will continue to play the most important role, guaranteeing that these programs will run well into the next decade.

Landsat-5 was originally launched in March 1984, and was planned to have a five-year lifetime. The satellite is working perfectly and is expected to fulfil its operational expectations for several more years.

SPOT-1 is also performing beyond its design expectations, and the 10-meter data has proven particularly useful in applications requiring a more accurate data source, such as

Table 1
LANDSAT 5 TM Bands And Their Applications (Lillesand and Kiefer)

Band No.	Band Width (μm)	Approximate Description
1	0.45 to 0.52	Visible blue/green: Provides maximum penetration of water, which is useful for bathymetric mapping in shallow water. Also useful for distinguishing soil from vegetation and deciduous from coniferous plants.
2	0.52 to 0.60	Visible green: Corresponds to the green reflectance peak of vegetation, and so is useful for assessing plant vigour.
3	0.63 to 0.69	Visible red: Radiation in this band indicates the level of chlorophyll absorption in plants, and so is important for discriminating vegetation types.
4	0.76 to 0.90	Infrared reflected by the earth's surface: Useful for determining biomass content and for mapping shorelines.
5	1.55 to 1.75	Reflected infrared: Indicates moisture content of soil and vegetation, penetrates through thin clouds, and provides good contrast between vegetation types.
6	10.40 to 12.50	Radiated or "thermal" infrared: Provides night time images useful for thermal mapping and for estimating soil moisture.
7	2.08 to 2.35	Reflected infrared: Corresponds to band of radiation absorbed by hydroxyl ions in minerals. Useful for mapping hydrothermally altered rocks associated with mineral deposits, particularly when compared with Band 5.

forest clear cut mapping. The stereo capability of this satellite has meant that topographic maps and digital elevation models can be derived entirely from the digital information.

The Landsat-6 satellite is currently being constructed for a July 1991 launch. Not only will this satellite have the successful TM sensor, but it will also provide Enhanced TM data with a 15-meter panchromatic resolution. This will supplement the availability of the SPOT 10-meter panchromatic data, which has proven to be extremely useful, especially when used in combination with the spectral information from the TM.

SPOT-2 is ready for an early 1990 launch and SPOT-3 is being built for a 1992 launch. All of these sensors will be the same, ensuring the continuity of the data source. SPOT-4 is being developed for launch in 1994. This will be an improved sensor, carrying the useful SWIR band for vegetation discrimination. 10 meter images will also be more easily attained with this new sensor as one of the multispectral bands is planned to have 10 meter resolution.

Of particular interest will be the increasing availability of radar data. Since radar sensors provide all-weather and day/night operation, they are able to provide data on demand, a key requirement in resource management. The first of the radar sensors will be launched on ESA's ERS-1 satellite in late 1990. This will be followed by the Japanese ERS-1 in 1992 and Canada's own Radarsat, currently scheduled for a 1994 launch.

As we have demonstrated, one of the key factors in developing an IRIMS is that the data source should be digital, as the ease with which information can be extracted from this data is really the key issue. Satellite sensors provide just one source of data and an important role will also be played by airborne sensors, such as MEIS or airborne SAR. These sensors are particularly important when there is a need for additional larger scale information.

For instance, the MEIS scanner provides spatial resolutions of 1 meter and above, and more importantly provides a spectral resolution of 8 selectable bands in a range from 400-1000 nm. This data has proven to be particularly useful to the Canadian Forestry Service who are able to identify the effects of insect infestation and other diseases in individual trees, a major forest management problem.

Applications

With the acceptance of remotely-sensed data as a viable data source for operational applications, more and more organizations are investing in the acquisition and development of customized systems to meet their specific operational requirements. These organizations are turning to this technology not simply to exploit technology for evaluative purposes (although this is often a first step), but because it makes sound business sense on a cost/benefit basis.

Table 2
Characteristic of Some of the Future Satellite Sensors

Sat	Launch	Life	Alt	Rev	Swath	Sens	Spectrum	Res	Use
SPOT-2	Jan 1990	3	832	26*	60	PLA	PANCHROMATIC	10	Cartography
					117	** MLA	GREEN RED NEAR IR	20	Thematic Mapping
Landsat	Mid 1991	4	705	16	185	ETM	PANCHROMATIC	15	Cartography
							VISIBLE	30	Thematic Mapping
							NEAR IR	30	
							SWIR	30	
							THERMAL	120	
ERS-1	Oct 1990	3	777	3	100	SAR	C-Band	30	Earth Obs
JERS-1	1992	2	568	44	75	SAR	L-Band	18	Earth/Ocean Observation
						OPS	VNIR	18	Land cover
							SWIR	18	Land cover
RADARSAT	1994	5	1000	1 *	130	SAR	C-Band	28	Ice/Vegetation Monitoring

* 5 Day Revisit Off-Nadir ** 2HRV Sensors Operating Side-by-Side

In Canada several organizations have taken a leadership role in incorporating remote sensing technology into their day-to-day operations. Two examples of such organizations are the British Columbia Ministry of Forests and the Ice Centre, Environment Canada. These organizations utilize large volumes of remotely-sensed data on a daily basis as part of their management and forecasting activities.

In the area of forest management remote sensing technology has proven to provide tangible benefits for such activities as:

- inventory mapping and update,
- forest sampling and plot analysis,
- regrowth monitoring,
- insect and disease assessment,
- forest change monitoring.

Substantial research in these areas has taken place, and the ability to use remotely-sensed data sources to address these activities is well defined and documented (Ahern and Leckie). This is not to imply that further research in this area is not required. It simply demonstrates that research performed to date justifies the use of remote sensing technology in an operational forest management environment. The issue that is now facing many organizations is that of implementing systems that maximize the return on investment in terms of tangible benefits to that organization.

The Inventory Branch of the British Columbia Ministry of Forests maintains a program to update approximately 6 600 1:20 000 scale forest inventory maps on a 2-year cycle, based on satellite imagery (Hegyi). In this case, the primary data source is the Landsat Thematic Mapper. These updates account for such forest changes as harvesting, fire and damage by insects and disease.

One other field in which the benefits of remotely-sensed data are well established is sea-ice mapping. In Canada the monitoring and forecasting of sea-ice movement is critical to the safe operation of shipping lanes and oil drilling platforms in eastern and arctic Canada. With the upcoming launches of several radar satellites (ERS-1, JERS-1, Radarsat) and the current availability of airborne SAR, operational forecasting of ice from digital imagery has proven operationally viable.

Perhaps the world's most advanced sea-ice forecasting implementation can be found within the Ice Centre, Environment Canada, a branch of the Canadian Atmospheric Environment Service. Recognizing the benefits of exploiting digital remotely-sensed imaging technology, and digital processing in general, the Ice Centre has undertaken a major expansion program involving the development and implementation of an integrated systems infrastructure.

In the spring of 1989, the Ice Centre took delivery of the Ice Data Integration and Analysis System (IDIAS), which was designed and built by MacDonald Dettwiler. IDIAS, the heart of the system, is a highly automated system that uses real-time digital data from a number of airborne and spaceborne imaging sensors to produce digital and analogue ice forecast products for eastern and arctic Canada on a daily basis. IDIAS can accept input image data volumes in excess of 500 MBytes per day from such sources as the Landsat TM, SPOT, NOAA AVHRR, Airborne SAR and SLAR. As well, IDIAS will accept data from ERS-1 and Radarsat once those sensors enter operation.

These two examples demonstrate organizations that have evaluated the benefits to be gained by utilizing remotely-sensed data and have successfully exploited the appropriate data and systems technology to address their unique operational applications. Other organizations, particularly in the forest resource management field, have recognized the benefits to be had from remotely-sensed data, and are acquiring the systems infrastructure required to successfully reap the benefits.

Summary

During the 1990s, Canada will witness a proliferation of integrated resource management systems designed specifically to address the requirements across the decision-making levels of operational organizations. For the full potential of these operational systems to be realized, a viable source of data must be available.

Fortunately, remotely-sensed imagery addresses many of those needs. The combination of spaceborne and aerial sources provides consistent, accurate and timely data in a cost-effective manner that is useful for numerous resource management applications. With the ever increasing number of remotely-sensed data sources, operational organizations can now implement systems to exploit this technology with minimal risk. In fact, it is becoming increasingly clear that now is the time for operational resource management organizations to implement systems to address their exacting requirements.

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Sustainable Development in GIS as a Component in Statewide Decision Support Systems

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Abstract
Earth Observations, their descriptive attributes and graphic annotations (maps), have historically been the three prime sources of data required for resource management decision making. During the past two decades of the seventies and eighties, Computer Aided Design (CAD) technology, emerging from the engineering disciplines, was embraced by the resources management community. Concurrently, high-resolution satellite imagery became available in digital form. Concomitant extension of database management into digital graphic applications, provided the integration methodology, the availability of low-cost computing, and the analytical capabilities for many users to take advantage of developing Geographic Information Systems technology. This included resource managers at the State level, where the basic mandate to meet agencies requirements, county demands and regulations at all levels, needed an economically viable means to monitor and update the information. Under these circumstances, a sustained GIS capability is not a choice but a prerequisite if the States are to meet their requirements and maintain control of their future growth.

Introduction

With respect to the management or general stewardship of the Nation's natural resources, this paper might be titled: "Sustainable Development in GIS as a Component in Decision Support Systems." In this regard, the states of the Union hold no unique requirements. Yet, the states do hold a unique responsibility in serving their constituencies in managing the state's resources. To successfully carry out their mandates, states must rely on their several agencies, county and local governments. All need current information provided on a timely basis. Traditionally, information required in resource management were derived from three primary data sources: Earth observations, their descriptions (statistics and attributes), and delineations (maps providing geographic referencing and depicting boundaries and cultural features). Unfortunately, by the time all these data came together in final format, the information was obsolete, and updating, if accomplished at all, was tedious and expensive. Such information in support of the decision making process, was marginal and not sustainable from a practical standpoint.

It is often said, "knowledge is power". According to Webster, knowledge is the orderly synthesis of information. Clearly, those who have "prior knowledge" (information) have a decided advantage in decision making over those who do not. Prior knowledge is defined here as the presentation and integration of information in a time frame and context not at all available by traditional means; that is, before rather than after the fact. Geographic Information Systems (GIS) having earth observations as their centerpieces, yield and maintain exactly these types of data, and when integrated with other geographically relevant information, provide a complete and fully current source of knowledge germane to the decision making process. Earth observations represent the "prior knowledge" component that provides the system dynamics required for sustainability and lifts GIS above a mere static phenomenon. Integrated data providing relational information represents the knowledge base need for intelligent statewide decision making.

Background

With the launch of the Earth Resources Technology Satellite (ERTS I) in July 1972, technology was demonstrated having the potential to dramatically change the way the world and its resources were perceived. By the time ERTS II, (now called Landsat II) was launched in 1975, the feeling was almost euphoric at the "better than expected" data being collected by the Multi Spectral Scanner (MSS). With the excitement, expectations grew beyond those ever intended for the system. While perhaps satisfactory on a project basis for government supported scientific research and development, the system was never designed to meet the rigourous criteria of the commercial marketplace.

The failure of Landsat to meet all its early expectations went beyond the lack of philosophical perspective and market commitment required for success. Technical considerations, beyond Federal government control, also played a significant role in the slow user acceptance of the data. Supporting technologies in geographic referencing, overlay and annotation were not in place, data base management methodologies for spatial applications were not developed, nor was the low-cost computing to accomplish all this available.

During the decade of the seventies, Computer Aided Design (CAD) technology emerged out of the engineering arena and found almost immediate acceptance in the resource management community. Concomitant extension of data base management methodology into digital graphic applications, provided the capability for the relational integration of graphic, attribute and statistical data into digital GIS configurations. The advent and subsequent explosion of microcomputer technology has put substantial GIS capability into the hands of virtually all serious users.

On February 21, 1986, the French launched the SPOT satellite into near-polar sun-synchronous orbit. Significantly, the SPOT program, represented in the United States by SPOT Image Corporation (SICORP), of Reston, Virginia, presented the first "made for commercial" venture in civilian satellite data delivery systems to the United States remote sensing user community. SPOT's contribution to the menu of available digital image products has been substantial, but not so much as a result of new additions of exotic technology. It has been rather, the innovative rearrangement of existing capabilities, and in packaging them to meet real and perceived market needs.

The Opportunity

From a statewide applications standpoint, the unique technical advancements represented by the SPOT satellite were significant. The linear array or "push broom" design of the two identical High Resolution Visible (HRV) instruments provide (1) broad band panchromatic data with a ground resolution of ten meters, and/or (2) multispectral data in three bands with a ground resolution of 20 meters. The nominal SPOT scene covers a 60 x 60 km area. When both HRV's are working in a twin vertical mode, there is a 3 km sidelap yielding a double swath width of 117 km. The planimetric mapping opportunities provided by these resolutions are significant.

Each HRV instrument is equipped with a strip selection mirror that allows viewing up to 27 degrees off nadir. Such oblique viewing provides a nominal scene with variable size, from 60 km vertical (nadir) to 81 km at the full off-nadir angle of 27 degrees. This capability provides a 950 km viewing corridor for each pass of the satellite. Within this corridor, two independent nominal scenes can be collected in P, XS or both simultaneously. The off-nadir viewing capability presents opportunities to image the same ground location from several different orbits and at several different angles. This capability provides for rapid revisits, by minimizing cloud effects, and stereo viewing, both in the P and XS mode. The topographic mapping opportunities provided by these capabilities are significant.

The opportunities presented go beyond the technological developments made over the past decade and a half. Less emphasized, but no less significant has been the substantial body of practical applications developed over this same period of time. Many of these were accomplished by state universities under federally funded programs variously called Applications Systems Verification and Test (ASVT), Applications Pilot Test (APT) and more generically, Technology Transfer. States, through their universities, were actively involved, and a wide range of projects were undertaken and applications were developed. In support of this activity, considerable, if not elaborate, facilities were installed.

With few exceptions, these projects and applications never matured enough to move to implementation, although most were well thought out and had merit. In virtually all the government projects and applications, image data not only were held up as the centerpieces of spatial information systems, but were considered as the only significant source of information in the system. Other data, if and when used, were brought in as ancillary additions. As funding was withdrawn from the various government programs, the pure image based information approach could not be justified at the state or local level. Facilities languished, but generally were not dismantled, as resources were reallocated to activities generating more revenue.

Earth observations represent the spatial context within which geographical information are cast, and from this point of view, imagery can honestly be considered the centerpiece for GIS, but imagery cannot stand alone. As the "prior knowledge" (before the fact) component of GIS, synoptic earth observations over large areas represents a place to start in lieu of little or no existing information. With the advent of higher resolutions (10 meter), broad area characteristics of the image remained, but the image contents have been lifted beyond the synoptic to the detailed representations of the landscape. This permits data base establishment, maintenance and update at very workable scales and at very attractive unit area costs.

In the world of 'high tech', nothing remains static very long. Dramatic changes in technology and agenda cast new light on the role of GIS, and provided great opportunities in the statewide decision making process. The data are in place, and products and services are being provided and are driven by the public and private marketplace. The supporting technologies not available during the remote sensing 'heydays' of the seventies, have been developed and implemented, and low-cost analytical capabilities are available for virtually all who wish GIS solutions. It is time to reassess the utility of image based geographic information systems in statewide schemes for information management.

Discussion

Issues of global change have attracted widespread attention and are currently receiving major emphasis. So long as the world population continues to grow and environmental, economic and social factors continue to thwart efforts to increase food production, this issue will remain a cause for concern. If the technically advanced countries of the World in general, and the United States, in particular, do not take the lead in resolving these issues, then we will stand in default while the rest of the world sets the agenda.

If the United States is to assume the lead in world information management technology, it must also set the example. Given that the whole is the sum of its parts, the ability of the United States to manage its natural resources is predicated on the ability of the individual states to manage their resources. State programs are carried out by the various state agencies, county and local governments. In addition, the state has the responsibility to meet and implement Federal and other regulatory guidelines. Environmental monitoring, urban and regional planning issues and the management of the state's forest and natural area resources, are compelling reasons for active GIS applications and development.

Geographic Information Systems utilizing earth observations from satellites are especially well suited to environmental monitoring and mapping. Single scenes provide current large area views (3600 square km per SPOT scene, for example) and yet have ground resolutions capable of producing accurate mapping scales to 1:24 000 and larger. This allows for the identification and map ping of small but critical land use/land cover features. Traditional techniques for measuring and mapping change are time consuming, labor intensive and costly.

Water runoff presents a serious environmental problem in many areas. Runoff, as it effects marine vegetation and fresh water supplies, remain areas of debate and enforcement. Studies conducted in the Delaware Bay area near Lewes, Delaware, demonstrated a strong correlation between calculated vegetative index (VI) and biomass as measured from satellite derived imagery. The study was replicated in time over a three-year period using both Landsat and Spot data. The high resolution of SPOT was very useful in mapping small estuaries and creeks entering the marsh. The results indicated wide variation in VI, as predicted by the biomass measurements, occurring spatially and temporally. (Klemas, et.al.,1987). Since vegetative index is also correlated with the marsh's productivity, such data are essential on a recurring basis to monitor and map overall productivity levels within the marsh.

Groundwater and non-point source pollution are major issues faced by the five water management districts of Florida. In a project loosely titled 'Land Use Mapping', the Northwest Florida Water Management District contracted Landmark Technologies of Jacksonville, Florida, to map and assess the major landforms and cover types in the coastal panhandle of Florida, near Panama City. Landmark elected to use data from the SPOT satellite to first update the USGS base maps. The most recent maps were from the U.S. Army in 1944. The high resolution, and inherent capability of multispectral data to differentiate land and water interfaces, provided an excellent means to update and map wetlands within the area of interest. Once the data capability became obvious through several field visits, the general nature of the project shifted to be more specifically one of wetland inventory. Deer Point Lake, just west of Panama City, is a major source of fresh water in the region. Large sod farms in the area tend to encroach on the natural drainage system, and dangerous levels of agricultural pollutants are finding their way into the Lake. The magnitude of this problem was not realized before this project.

Being in the recently uplifted lower coastal plain, the Florida Panhandle is covered with residual depressions, variously called ponds and bays. These physiographic structures are heavily vegetated with a variety of tree and brush species, and range in size from fractions to hundreds of hectares. The larger and deeper ones tend to remain the same except for encroachment along the margins. The smaller features are being heavily impacted by cultural conversion carried on by the two major pulp and paper companies in the area, in order to increase their productive acreage. The Water Management District is interested in monitoring the rate of this land conversion, its pattern and possible impact on the future water supply for the region. It will take a sustained information system (GIS) to help the District monitor the management of the area, and to provide the basis for intelligent regulation, if such is required.

Direct pollution from toxic dumping is a continuing concern for environmental management. The identification and mapping of illegal sludge pits and oil spills, which are a significant hazard to wildlife in petroleum production areas, is difficult because of their wide spread and rather random locations. In a study conducted by the College of Agricultural Sciences, Texas Tech University, a 1951 square km (750 sq. miles) area near Denver City, Texas was selected to evaluate the ability of SPOT data to detect and map such features (Fish, 1988).

It is estimated that several hundred or even thousands of these illegal oil deposits currently exists in scattered locations across the oil production areas in west Texas. The pits are diked earthen structures designed to catch overflows or spills of oil and oil/water mixes from tank batteries or pump sites. They vary in size from as small as 12 square meters to 12 hectares or more. These pits are so pervasive that it is estimated upwards to 220 000 birds are killed annually as a result of contact with these deposits.

Locating pits and spills through traditional means is not feasible, given the currently available resources. The use of digital SPOT imagery allowed very large areas of land to be surveyed quickly and cost effectively. Enhancement of the spectral bands helped investigators discriminate the targeted sludge pits from similar appearing features such as open water bodies, wet soils, asphalt and sewage lagoons. The algorithms and methodology developed during this project are directly transferable into ongoing operational information systems.

Perhaps no area has been impacted more by GIS than the urban and regional planning disciplines. This is true for both the broad land cover classifications and the basic updating and maintenance of the existing line maps. This capability has effected the regional and county planning departments and the engineering firms they use to accomplish their mapping tasks. Proposed highway corridors represent a special mapping problem faced by the planners. Demographic patterns, wetlands and many other cultural considerations must be weighed in designing the routes for these corridors. Here, it is essential that current maps be generated as a prerequisite. Landmark Technologies of Jacksonville, Florida, was involved with the local engineering firm of Prosser, Hallock & Kristoff, Inc., in mapping alternative road corridors around the city of Jacksonville, as a preliminary to designing an outer beltway around the city.

The area, a 45 km x 6 km (28 miles x 6 miles) swath northwest of Jacksonville, was quickly and accurately classified. Especially important to the Department of Transportation were the fertile transition zones between wetlands and the mesophitic uplands. Because of the combination of soil characteristics and vegetative association, SPOT data delineated these areas with precision. Three corridor alternatives, each 1.2 km (4 000 feet) wide, were digitally overlaid on the classified image. Once the preliminary assessments were made the engineers could efficiently plan the aerial photographic mission for the selected route, only 122 m (400 ft.) wide. This project was completed at roughly one sixth of the cost normally incurred for such a task.

The matter of the nation's forests, their management and regulation is becoming of increasing concern. Whether it is public or private timber, there is pressure to fulfil wide ranging agendas, not necessarily compatible with the objective of ownership. The forest is a dynamic entity, and to establish its extent, structure and condition is tedious and costly. In addition, once the job is complete, it is obsolete, so the ability to monitor and update in a timely fashion is absolutely necessary if the information required for decision making is to be current and pertinent.

Satellite image based GIS's have utility in forestry applications as they did in other environmental issues. In fact, one of the strong points for wide area generalized coverage provided by SPOT data, is the wide variety of interests represented on one scene.

Using the same data set as previously described in the road corridor selection process near Jacksonville, Florida, a subset of some 14 000 ha (35 000 acres) was analyzed by Landmark Technologies to demonstrate the capability and cost advantages of the approach in forestry applications. The data were formatted and geometrically corrected. Ancillary data from USGS 7.5 minute quadrangle maps were used to capture the public land survey data of township, range and section, and other cultural features. These data were then integrated with SPOT data, clustered and classified. Aerial photography, flown a year previously at a scale of 1:15 840, was typical of photography used for forest planning purposes. The cover typing and digitizing of these photographs were accomplished, and the cost was used for comparison.

It was demonstrated that the SPOT data were at least as accurate as the photo-interpreted results. More impressive were the cost estimates which were 2 to 1 in favor of SPOT data. Initial inventory is costly and requires the greatest amount of field activity to establish a sound basic database.

The utilization of SPOT and selected site specific aerial photography as ancillary data should reduce, if not eliminate, the need to ever repeat an inventory from scratch.

To compound the state's resource management and monitoring needs, regulation demands at the county and local levels are increasing. When more than one county is involved, or where the general good of the state is involved, the states, too, are being pressured to enact statewide regulations. The degree of involvement depends on the state and its willingness to allow local autonomy. While the turf battles are just beginning as to who has the regulatory responsibilities, the reality of regulation is here, and pressures to increase the controls on how public and private lands are administered are being felt. Whether it be tree preservation, road degradation or smoke management, the effectiveness and fairness of implementation rests on the state's ability to define and monitor its own resources. To do this, a sustainable GIS capability is not an option, but a necessity.

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Remotely Sensed Data: Sensors, Coverage, Data Availability and Access, Cost

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Abstract
This paper reviews the various sensors which currently generate remotely sensed data, the coverage available, availability of and access to the data, distribution media-analog or digital, and ordering mechanisms. Private sector involvement in data distribution is described and the Canadian radar satellite is discussed.

Introduction

The Canada Centre for Remote Sensing (CCRS), established as a branch of the federal Department of Energy, Mines and Resources on April 1, 1971, is the central agency in the nationwide remote sensing program. A major activity of the program is the collection and distribution of remotely sensed data. This activity includes the operation of two satellite receiving stations, one at Prince Albert, Saskatchewan, and a second at Gatineau, Quebec, for the reception and archiving of remote sensing satellite data. The ground stations receive data from the American Landsat series, the National Oceanic and Atmospheric Administration (NOAA) meteorological satellites, the French SPOT-1 satellite, and more recently, the Japanese MOS-1 satellite. CCRS is preparing for the reception, processing and distribution of data from the Synthetic Aperture Radar aboard the European Space Agency satellite ERS-1 scheduled for launch in 1990 and for RADARSAT, to be launched in 1994.

This paper will discuss the various sensors generating remote sensing data, the coverage available, access to the data, and describe the products produced by CCRS from this data. It will describe private sector involvement in the data distribution, and discuss RADARSAT, Canada's first Earth Observation Satellite.

Landsat Sensors

The first of the Landsat series of satellites was launched by the United States in 1972. Each one has carried electro-optical sensors: the Multispectral Scanner, which has been in use since 1972, and the Thematic Mapper, which began transmitting images in 1982.

Table 1: Landsat Sensors

Multispectral Scanner (MSS)

Swath Width	185 km	
Spatial Resolution	80 m	
Spectral Bands		
1	0.50 - 0.60 micrometer	(green)
2	0.60 - 0.70 micrometer	(red)
3	0.70 - 0.80 micrometer	(near-infrared)
4	0.80 - 1.10 micrometer	(near-infrared)
Radiometric Resolution	64 gray levels	

Thematic Mapper (TM)

Swath Width	185 km	
Spatial Resolution	30 m	
Spectral Bands		
1	0.45 - 0.52 micrometer	(blue)
2	0.52 - 0.60 micrometer	(green)
3	0.63 - 0.69 micrometer	(red)
4	0.70 - 0.90 micrometer	(near infrared)
5	1.55 - 1.75 micrometer	(shortwave infrared or SWIR)
7	2.08 - 2.35 micrometer	(shortwave infrared or SWIR)
6	10.5 - 12.5 micrometer	(thermal infrared, resolution 120 m)
Radiometric Resolution	256 gray levels	

Multispectral Scanner (MSS)

Images produced by the multispectral scanner cover an area of 185 km by 185 km or approximately 34 000 km². The sensor's ground resolution is 80 metres and it's radiometric resolution is 64 gray levels. It produces images in four spectral bands: one in the green portion of the spectrum, another in the red, and two in the near or reflected infrared.

Thematic Mapper (TM)

The Thematic Mapper is an improved sensor which features more spectral bands, seven versus four, along with better spatial resolution and improved radiometric resolution. The sensor covers an area of 185 km x 185 km with spatial resolution of 30 metres and its radiometric resolution is 256 gray levels.

The TM spectral bands are normally used in combinations. However, a description of each of the TM bands is given in Table 2 for the reader's general information.

Table 2: Single-band descriptions of TM sensor

Spectral Bands	
1	0.45 - 0.52 micrometre (blue) Not recommended for use alone because of low contrast and sensitivity to haze.
2	0.52 - 0.60 micrometre (green) Not recommended for use alone because of low contrast and sensitivity to haze.
3	0.63 - 0.69 micrometre (red) Best for showing roads and other non-vegetated features. Not particularly useful for identifying waterbodies. Minimal conifer-deciduous contrast.
4	0.76 - 0.90 micrometre (near-infrared) Best for conifer-deciduous contrast and burned areas. Also useful for delineation of waterbodies.
5	1.55 - 1.75 micrometres (shortwave infrared) Best single band overall. Excellent haze penetration. Waterbodies and variations in forest composition are visible.
6	10.5 - 11.5 micrometres (thermal infrared) This spectral region responds to the thermal (heat) radiation emitted by the target. This band presents some difficulties for multispectral analysis or band combinations because of lower resolution (120 m). The band offers some potential in geothermal and hydrogeological applications.
7	2.08 - 2.35 micrometres (shortwave infrared) This is another reflective IR band but has even greater haze penetration ability than band 5. Image quality, however, is generally poorer since it has a lower signal-to-noise ratio.

SPOT-1 Sensors

Launched by France in 1986, the SPOT (Systeme pour l'observation de la Terre) spacecraft carries two nominally identical High Resolution Visible (HRV) imagers and is designed to operate in either of two modes, a panchromatic (PLA) mode or a multispectral (MLA) mode. In addition, the SPOT HRVs are pointable across the track allowing access to areas other than those directly below its path.

MLA (Multilinear Array)

Images recorded in the MLA mode have a swath width of 60 km for nadir viewing and 80 km for extreme off-nadir. The ground resolution is 20 metres and the radiometric resolution is 256 gray levels. The MLA produces images in three bands similar to Landsat's MSS green, red, and near-infrared bands.

PLA (Panchromatic)

Alternatively, the sensors can provide black and white images with a high 10 metre resolution and a radiometric resolution of 64 gray levels.

Table 3: SPOT-1 Sensors

	PLA	MLA
Swath Width	60 or 117 km	60 or 117 km
Spatial Resolution	10 m	20 m
Spectral Bands	0.51 - 0.73 micrometer	0.50 - 0.59 micrometer (green) 0.61 - 0.68 micrometer (red) 0.79 - 0.89 micrometer (near infrared)
Radiometric Resolution	64 gray levels	256 gray levels

MOS-1 Sensors

The Japanese Marine Observation Satellite (MOS-1) was launched on February 19, 1987. An amendment to the Arrangement between CCRS and the National Space Development Agency of Japan (NASDA) permits CCRS to continue to receive and sell MOS-1 data. MOS-1 carries three earth-observation radiometers: a Multispectral Electronic Self-Scanning Radiometer (MESSR), a Visible and Thermal Infrared Radiometer (VTIR), and a Microwave Scanning Radiometer (MSR).

MESSR

The MESSR is an electronic scan-type radiometer which detects reflected solar rays from the earth's surface in two visible bands and two near-infrared bands. It's objective is the observation of sea-surface colour and land use. It is equipped with two camera systems that are parallel to the direction of flight of the satellite. Each system scans a swath of 100 km. When the two systems are used at the same time, a swath of 185 km can be scanned. The ground resolution is 50 metres.

VTIR

The VTIR uses one visible band and three thermal infrared bands to detect thermal radiation to provide information on the distribution of atmospheric water vapour and surface temperature. The scanning width of the VTIR is 1,500 km and the ground resolution is 900 m in the visible band and about 2700 m in the thermal infrared bands.

MSR

The MSR continuously scans the earth's surface conically for a swath of 317 km as the satellite travels. During this process the MSR receives weak radio waves in the two frequency bands of 23.8 and 31.4 GHz. Its resolution is 32 km in the 23.8 GHz band and 23 km in the 31.4 GHz band. The MSR will survey snow, ice, and water vapour by monitoring micro-wave radiation from the earth's surface.

Table 4: MOS-1 Sensors

Multispectral Electronic Self-Scanning Radiometer (2) (MESSR)

Swath Width	100 km
Spatial Resolution	50 m
Spectral Bands	1 0.51 - 0.59 micrometer (green) 2 0.61 - 0.69 micrometer (red) 3 0.73 - 0.80 micrometer (near infrared) 4 0.80 - 1.10 micrometrer (near infrared)

Visible and Thermal Infrared Radiometer (VTIR)

	Visible	Thermal Infrared
Swath Width	1500 km	
Spatial Resolution	900 m	2,700 m
Spectral Bands	1 0.5 - 0.7 micrometer	2 26.0 - 7.0 micrometer 3 10.5 - 11.5 micrometer 4 11.5 - 12.5 micrometer

Microwave Scanning Radiometer (MSR)

Swath Width	317 km	
Spatial Resolution	32 km	23 km
Frequency Bands	23.8 GHz	31.4 GHz

NOAA-AVHRR Sensors

The Advanced Very High Resolution Radiometer on board the National Oceanic and Atmospheric Administration meteorological satellites records data in 5 spectral bands with a spatial resolution of 1.1 km. It has an almost circular orbit approximately 840 km above the earth and crosses the equator on its ascending pass in the afternoon and on its descending pass in the middle of the night.

Table 5: NOAA-AVHRR

Swath Width	2500 km
Spatial Resolution	1.1 km
Spectral Bands	0. 58 - 0.68 micrometer (red) 0.725 - 1.10 micrometer (near infrared) 3.55 - 3.93 micrometer (infrared) 10.5 - 11.3 micrometer (thermal infrared) 11.5 - 12.5 micrometer (thermal infrared)

Available Coverage
Data is received of all passes within the coverage capability of the two CCRS reception stations under the CCRS Satellite Reception and Image Archive Policy.

Landsat 5 and SPOT 1 are routinely recorded from 15 March to 31 October. Landsat 4 MSS reception is on demand only from 15 April to 15 September. NOAA-AVHRR reception on demand from 15 April to 15 September and MOS-1 will also be tracked on demand.

To ensure that representative and useful satellite imagery of Canada exists and is accessible for retrospective studies, CCRS maintains an archive of data sets from the previous Landsat satellites as well as currently recorded data. A copy of the complete CCRS Reception and Archive Policy may be requested from the User Assistance Unit, CCRS, Ottawa.

Data Access
If you are interested in data availability for a particular area CCRS maintains several 'aids' to assist your search. First, there is QUERY, a utility computer program to interrogate the CCRS imagery data bases using your search criteria to generate a listing of available scenes. The service is free and covers Landsat 1 to 5, SPOT-1, and MOS-1.

A second source of information is the imagery of Landsat and SPOT on microfiche which permit preliminary evaluation of image quality and cloud cover. Every image acquired is reproduced on microfiche. The fiche is available for viewing at CCRS and various provincial centres or may be purchased through the Prince Albert Order Desk. CCRS also produces hard-copy catalogues listing the imagery in our Landsat and SPOT data bases. Both the catalogues and microfiche are organized by the Landsat World Reference System of path and row and by the SPOT Ground Reference System. Landsat Index Maps and the Catalogues are available from User Assistance at CCRS, Ottawa.

Products
CCRS processes remote sensing data using MOSAICS, the Multi-Observation Satellite Image Correction System at the Prince Albert Satellite Station facility.

MOSAICS produces a full range of products from geometrically raw to precision geocoded and offers flexible product options to suit the user's needs. Geometric corrections are calculated for sensor and platform, as well as earth geometry. Output products are available in a radiometrically raw form, or with full radiometric corrections. Products can be framed in a variety of ways. Bulk products can be framed using the standard reference systems for each satellite, WRS for Landsat, or GRS for SPOT, with products being identified by standard path and row indicators. As well, bulk products can be specified by a latitude and longitude value for the scene centre. In addition, Landsat TM quadrant products may be produced for the four standard quadrants and eight offset quadrants. Geocoded products are specified by a map sheet identifier corresponding to a 1:50 000 scale National Topographic System (NTS) map. In addition to the standard radiometric corrections, CCRS offers users the option of specifying a radiometric enhancement for film products. The enhancement can take the form of a histogram based contrast stretch, a sun angle or haze correction, a reflectance enhancement, a multiplicative enhancement or a custom enhancement defined specifically for that particular product.

All MOSAICS products are available on CCT in the standard Landsat Ground Stations Operators' Working Group (LGSOWG) format. This standard family of formats allows products to be recorded at either 6250 or 1600 bpi, in either band interleaved by line (BIL) or band sequential (BSQ) format.

Any product can be requested as a film image, in either black and white (B/W) for single band images, or in colour for combinations of three bands. There is no restriction on the bands that are exposed on film. This flexibility in band selection coupled with the capability to apply a wide variety of standard and custom radiometric enhancements affords users a high degree of choice.

Table 6: MOSAICS Products and Correction Options

MOSAICS produces the following full range of products:

- Precision-corrected geocoded subscene
  - projected to a geoid at mean sea level,
  - rotated to UTM projection,
  - full radiometric and geometric correction with ground control points (GCPs).

- Systematic-corrected geocoded subscene
  - along-scan and across-scan geometric corrections, (no GCPs) and radiometric correction,
  - rotated to UTM projection.

- Geo-referenced full-scene and quadrant (TM only)
  - full radiometric correction and along-scan geometric correction only (no GCPs).

- Raw full-scene and quadrant (TM only)
  - no radiometric or geometric corrections.

NOTE: Full radiometric correction includes both relative and absolute correction.

Ordering
All product requests should be directed to:

ORDER DESK
Prince Albert Satellite Station
Energy, Mines and Resources Canada
P.O. Box 1150
Prince Albert, Saskatchewan
S6V 5S7
Telephone: (306) 953-8540
FAX: (306) 953-8573

Telephone orders will be accepted but they must be confirmed by FAX or mail before production will begin.

The request should include:

- satellite and sensor,
- date of preferred coverage - from/to,
- maximum cloud-cover acceptable,
- product required,
- brief description of user's application,
- location - Landsat WRS path and row and/or latitude and longitude coordinates.

NOTE: User may preselect the scene required using CCRS catalogs, microfiche, or "QUERY" system.

The User Assistance and Marketing Unit, CCRS, Ottawa is the contact point for all requests for general information and applications oriented advice.

Telephone: (613) 952-2717
FAX: (613) 952-7353

Private Sector Involvement
An important part of the CCRS mandate is to assist the remote sensing industry in Canada. From the very beginning the Centre's operational style has been industry oriented. A wide variety of contractual arrangements for the development of required systems and the provision of both satellite and airborne data and services has met the needs of the Canadian user community and served as a means of technology transfer. A continuing example of this style is the operation of the CCRS satellite receiving stations reception, archiving, and production systems by Canadian industry from 1972 through to to-day. A new dimension to the industrially oriented operations of the Centre will begin in 1990 with the commercialisation of data production, distribution and marketing in Canada for Landsat and SPOT data. The Government (through CCRS) will continue to be responsible for the reception and archiving activity and for the maintenance of the archived data catalogue. Industry will be completely responsible for responding to the needs of the user community for data products. Industry will be loaned the Canadian MOSAICS production system and will have complete financial responsibility and complete freedom in both market and product development. The program initially involves data from Landsat and SPOT, however, the plan is to expand the industrial responsibility for commercial opportunities to other satellite programs, including both ERS-1 and, of course, RADARSAT. It is felt that this concept ensures the continuity of the National commitment to remote sensing by having the Government responsible for the maintenance of the data archive while at the same time providing industry with the means and incentive to develop the continued use of remote sensing as a tool for resource and environmental management.

RADARSAT
Canada's first Earth Observation satellite received final approval on September 13, 1989 when the Minister of Industry, Science and Technology Canada signed a Memorandum of Understanding with nine provincial partners on participation in the Canadian-led international RADARSAT project. Also, a Memorandum of Understanding outlining the responsibilities and cost-sharing arrangements of international partners to this project has been negotiated with the United States National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce. To promote the global use of RADARSAT data, the federal government has also negotiated a Memorandum of Understanding with a new Canadian company called RADARSAT International. Apart from the data rights retained by the Canadian and U.S. governments, this company will be assigned the sole rights to market all RADARSAT data internationally.

RADARSAT will be launched on a medium-class NASA rocket into a circular, sun-synchronous polar orbit. The satellite will circle the earth at an altitude of 800 kilometres and will complete approximately 14.4 orbits during a 24-hour period at a rate of 100 minutes per orbit. The satellite will cross the same point at the equator every 16 days and cover the Arctic daily. RADARSAT is planned to operate in space for a minimum of five years. The payload module of the satellite consists of the synthetic aperture radar (SAR), whose antenna will be 15 metres long and 1.5 metres wide when unfolded in space.

Compared to conventional radar satellites, the SAR will be versatile and innovative. It will provide a great deal of flexibility in the amount of coverage, the angle of observation, the ability to zoom in for higher level of detail for a smaller area or out for less detail of a larger area. The antenna will be able to point its beam anywhere within a swath of 500 kilometres between 20 and 50 degrees off the satellite's orbital path.

RADARSAT will provide valuable economic and scientific information on ice conditions, forests, and geological formations. The satellite's ability to collect data through darkness and cloud will be particularly useful in penetrating the almost constant cloud cover of the equatorial rain forests and Canada's coastal regions.

Data Issues and Remote Sensing

Session F2
Survey Control

Developing the Foundation: A Geographic Coordinate Data Base for Forest Resource Planning

High Altitude Laser Profiling For Vertical Control in Small and Large Scale Mapping.

An Introduction to the Global Positioning System and its Use in Ground Truthing Spot Satellite Imagery

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Developing the Foundation: A Geographic Coordinate Database for Forest Resource Planning

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Abstract
The U.S. Department of Interior, Bureau of Land Management, Oregon State Office is in the final stages of developing a 7 000 000 acre data base to support natural resource management planning efforts for the 1990s. Crucial to this effort has been the development of a Geographic Coordinate Data Base (GCDB) utilizing Public Land Survey Coordinate Computational System (PCCS) software. The process involves abstracting cadastral survey information and computing 'as surveyed' coordinates to serve as the base registration for the remainder of the data base. This paper will provide an overview of the process, a view of the impact on GIS processes, and the future development of the GCDB nation-wide by BLM and Infotec.

Introduction

Infotec Development Inc. has been the GIS/ADP computer support services contractor for the BLM Oregon State Office for the WODDB project since 1986. Infotec has also been awarded two contracts by BLM for development of GCDB data on a national scale. This paper approaches the subject of GCDB development from the perspective of a support services contractor.

The Western Oregon Digital Data Base (WODDB) is a U.S. Department of Interior, Bureau of Land Management (BLM) project to develop a digital data base to support Resource Management Plans (RMPs) scheduled for completion in the early 1990s on BLM lands in western Oregon. The project has involved the digital mapping of over 7 000 000 acres at a scale of 1:4800 and now includes a substantial number of thematic layers.

The accomplishment of the project in the very tight time frames required the development of a sophisticated tool box of hardware, software, and personnel. One of the key tools was processing and software to link the data base to the 'real world' in terms of cadastral survey accuracy. This was necessary to alleviate inaccuracies in existing map products, and to avoid being required to digitize geo-reference points repeatedly throughout the project.

Background

Historically, the basis for most of the digital data utilized in BLM GIS data bases has been derived from existing maps. Most of these maps were old, intended for other purposes, and in most cases, simply 'cartoons' of the real world. The WODDB project started with new aerial photography, the best available established geodetic control, and a scale of mapping that could provide a tremendous level of detail for the field user. The problem was to register this mass of digital information accurately to the surveyed world.

PLSS

In order to understand the complexity of the problem, a basic understanding of the U.S. National Public Land Survey System is necessary.

A. Basics of the PLSS Today

Starting with the Land Ordinance of May 20, 1785, which provided for surveys of public lands within the state of Ohio, a variety of acts, ordinances and manuals of instruction, accompanied by changes in governmental responsibilities, resulted in a very large and complex Land Survey System. There are various kinds of projection data systems, different storage methods and various data recording procedures, including computerized, micro-fiche, or simply a copy of an original linen. Every agency or entity has its own methods or priorities depending on the need, funding or political concerns. Thus, surveying data is scattered, not standardized and at times, out of date.

Whatever the form of the data, certain basic features are common in the PLSS, including:

1. Independent Initial Point,
2. Base Line,
3. Standard Parallels,
4. Meridians,
5. Townships,
6. Sections,
7. Subdivision of Section,
8. Irregular Tracts, and
9. Mineral Surveys.

B. Kinds and Sources of PLSS Data

PLSS data may be obtained from a wide variety of sources, including at least those described below.

1. Cadastral Survey Plats and Field Notes

The primary and major component of the PLSS is cadastral survey plats and field notes. These plats and field notes are stored mostly on microfiche at state BLM offices. Surveys of some military reservations and some Indian reservations that were subdivided for Indian allotments have not been put on micro-fiche and are available from hard copies only.

2. Rectangular Surveys

The most common type of cadastral survey plats and field notes is the rectangular survey. The majority of the western states have rectangular land surveys. In the states covered, there are 26 initial points of the rectangular survey. From these initial points, locally named principal meridians and baselines were established. Townships 6 miles square were laid out and referenced to the principal meridian and baselines.

3. Special Surveys

Special surveys involve unusual applications or departures from the rectangular system, and are of at least six kinds:

A. Tract and Lot Survey,
B. Townsite Survey,
C. Small Tract Survey,
D. Metes and Bounds Survey,
E. Mineral Survey,
F. Millsite Survey.

4. U.S.G.S Topographic Maps

USGS topographic maps show improvements that have been placed upon the ground and may be referenced to the PLSS corners. In areas where blunders and gross discrepancies exist, these maps can aid in determining where the error should be left. Also, some of the PLSS corners have been identified on photographs, and their locations are sometimes shown on the USGS topographic maps.

5. Control Diagrams

USGS and NGS Control Diagrams and Lists give the location and geographic coordinates of the main government geographic control points established in the field.

6. Status Maps

These maps provide the status of all federally owned land. Also shown are mineral rights, mineral leases, mining claims and road, powerline, pipeline and other utility rights-of-way.

7. Protraction Diagrams

Protraction diagrams present plans for extension of the rectangular system over unsurveyed public lands, based upon computed values for the corner positions. These diagrams, in the lower 48 states, are commonly used to identify mineral leases and mining claims in unsurveyed lands.

8. Connection Sheets (Mining Districts)

Connection Sheets show all the mining claims in a mining district. In some areas, supplemental sheets are available to show all the mining claim surveys. From these sheets, one can determine the approximate locations of mining claims and the names and survey numbers of mining claim surveys. Connection sheets are indexed by mining district.

9. Aerial Photos

Aerial photos are available for most areas from government agencies and USGS. In others, state, county, local governments and private sources have complete or partial coverages of the area. From photos, one can determine land use patterns which can help in identifying where survey blunders may have occurred in the PLSS.

10. Survey Records (state, county, private, etc.)

Many records of PLSS corners were created by state, county, private individuals, utility companies, etc. Utilities, while performing their field surveys, tied into PLSS corners along the route of the utility line in order that legal descriptions could be written for the line and access descriptions. Many of these surveys have already been tied into the State Plane Coordinate System and have field geographic coordinates on them.

All types of private surveys have been performed on PLSS corners but the availability of the records varies in different states and localities. These records are found mostly on mylar or paper, and are referenced in many different ways. Most indexes are referenced to the index system in use by the federal government for the PLSS, but modified to suit their individual needs.

11. Right-of-Way Descriptions

Many right-of-way descriptions have been written for access and utility purposes. With different degrees of accuracy, these descriptions have been tied into the PLSS corners. In many cases by using aerial photos, 7 1/2 minute USGS series maps, etc., the geographic location of the PLSS corners called for in the right-of-way description can be determined. Right-of-way descriptions are indexed on the master title plats of federal lands.

12. Special Situations (Eastern States)

In the states of Ohio and Indiana, there are eight public land rectangular surveys with no initial point as an origin for townships and range numbers. These surveys are indexed by survey name. They were the surveys used to structure the present day rectangular system of surveys. No rectangular surveys were performed by the federal government in the colonial states. In these states, metes and bounds surveys were privately performed. Terrain and physical features called out in legal descriptions is what mainly controlled these surveys. These private metes and bounds surveys are filed by many different indexing systems in the different counties.

PCCS

As can be seen, the PLSS is a very complex source of information. Using any digitizing process for data base construction from most of these sources will make it very difficult to achieve any quality or reliability. To address this problem, Mr. Bill Ball, BLM Denver Service Center, developed the Public Land Survey System Coordinate Computational System (PCCS) which was brought to Oregon in 1986 as a Beta test. The software was so successful that it was adapted as part of the WODDB effort. By the end of 1988, 377 townships had been processed through PCCS for the WODDB effort and entered into a data base (GCDB).

A. Methodologies

Abstraction, data input/data entry, digitizing and computation are the major procedural categories within the GCDB development process. The sections immediately below discuss each of the procedural categories with special emphasis on how they relate to the achievement of a high quality, accurate and complete GCDB.

1. Data Abstraction

Abstraction involves the translation of surveyor notes, plats, maps, diagrams and other survey information into a listing of bearings and distances which define the surveyed locations of PLSS corners in a township. The process of abstracting data is very exact. The first step involves identification of all source documents available for a given township. Next, the type of control in the township is determined. Third, data for adjacent townships are examined to determine which township contains the most recent (or best) survey data for the township boundary. Finally, all source documents for the township are examined to identify the one from which PLSS corner information will be abstracted. Only after all documents have been examined and those of the highest quality have been identified, does the surveyor begin to abstract information.

The township boundary is abstracted first, followed by the section lines. If irregular lotting exists, these are abstracted only after the surveyor again examines the survey notes to verify how the lotting was accomplished. Any special surveys (small holding claims, homestead entry surveys, U.S. surveys, townsite surveys, tracts, etc.), grant boundaries, mileposts, mineral surveys and meanders are also abstracted. For each corner abstracted, the surveyor records bearing, quadrant, distance, elevation, control, type of survey line, source, origin and average terrain elevation on the appropriate abstract form.

If there are many non-rectangular surveys in a given township, the PLSS corners from the non-rectangular surveys may be captured by digitizing, rather than abstraction and calculation.

During the abstraction process each corner abstracted is identified with a unique point identification code. The point ID code is a mathematically logical system for identifying all points in a township. The origin is taken as the SW corner of the township, and assigned an ID of 100100. This six digit number consists of two parts. The first three digits define the distance east of the west boundary of the township, while the last three digits define the distance north of the south boundary. Each section line is represented by an even 100 number. Points intermediate to section lines are assigned numbers based on the number of chains north and east of the section lines. All non-rectangular survey corners are assigned point IDs such that the first three digits indicate the type of survey. The last three digits are used for sequencing of the survey lines. After all PLSS corners have been abstracted, the parentheticals for the township are determined. Parentheticals are usually 1/16 corner points that will be computed by the PCCS programs based on the locations of 1/4 corners. These parentheticals are marked on the survey plat and entered on the Section Abstract Sheet. Next the geographic center of the township is determined. This is a reference point that is utilized by several of the PCCS programs to compute tangent plane coordinates and geographic coordinates. The township center or origin is computed in most cases by adding 3 minutes latitude and 3 minutes longitude to the coordinates of the SW corner of the township. Since this point is for reference only (i.e., like a 'seed'), it need not be known precisely. The origins for townships which are not close to square will need to be determined by the surveyor and recorded on the abstraction forms.

2. Data Entry

Data entry involves input of data from abstraction sheets into a computer. Each of the PCCS data entry programs uses a prompted entry system, i.e., the operator is prompted for each bit of information required by the program. Two pathways have been developed for initial data entry. The first requires a surveyor to input data from abstraction sheets using a direct data entry program. The second utilizes a data entry person, at lower cost, to input abstracted data utilizing a raw data entry program. A surveyor will later review and organize the raw data entered by the data entry person. Data is entered into the PCCS system in a specific order. Every program prompts for the township, range, meridian, and state first. Next, the point ID, coordinates and elevation of any control points (at least two are required) located in the township are entered. All bearings are entered and stored in compressed degree-minute-second format, which are expanded automatically prior to computations by the PCCS programs. This part of the file is referred to as the control section. Standard rectangular township survey data may be entered using any of the following programs: raw data entry, direct data entry, or control station coordinate file.

The survey measurement data subsection begins with entry of the township boundary data. This consists of the point ID for the starting point, point ID for ending point (TO/FROM), the bearing, quadrant, distance and elevation (if known). Boundary lines are entered starting with the eastern boundary, entering data from south to north. The remaining south to north section lines are then entered, working to the west, followed by the east to west section lines, the most southerly line entered first.

Non-standard rectangular portions of townships and special surveys are entered separately using a different program. In this program, initial data entry is identical to that required by standard townships: prompts for township, range, meridian, and state, followed by entry of control point data. The order of input of survey measurement data is up to the discretion of the data entry person. The order will usually be determined by the surveyor as they abstract the data initially.

3. Digitizing

Capture of PLSS corner coordinates using the digitizing process requires the use of a digitizing tablet and the computer editor software. Digitized coordinates are incorporated into the GCDB database only under the following two conditions: coordinates are needed from positively identified PLSS corners from USGS Quadrangle Maps such as 7.5 minute,or 15 minute quads, coordinates are also needed from PLSS corners shown on accurately drafted BLM Cadastral Survey Plats, where the time required to calculate corner coordinates using PCCS programs would greatly exceed digitizing time. Digitizing is usually employed to capture corners from small parcels of land such as mining claims, small survey tracts, or small with holding claims.

4. Computations

The computation part of the GCDB project involves selection and use of the PCCS programs for evaluation and adjustment, creation of PGCF files, subdivision of sections, graphics (PGCO), interfacing PCCS to other programs, and creation and maintenance of the PCCS database. PCCS programs are simply analytical procedures. The computation programs are designed to not introduce mathematical error into the process. Therefore, coordinate results of PCCS programs reflect the inherent accuracy of the original survey data abstracted from plats or survey notes. The knowledge and skill of an experienced cadastral surveyor is required to properly process data through the PCCS system. An experienced surveyor must analyze the data and determine which analytical computations should be performed to properly process the data.

5. Evaluation and Adjustment

There are two types of evaluation and adjustment programs, those which provide evaluation only, and others which will adjust the data and provide evaluation of the adjustment process. The main options are: the use of previously computed coordinates (usually township boundary) as fixed reference points for adjustment of interior corners, selection of network adjustments (all points in a township) or adjustment of an individual traverse line, and how extensive a report is required (original data + adjusted data + adjustment results or just adjustment results).

B. Interfaces

Programs are available for translating PCCS PGCF-type files into ADS(BLM's digitizing software), ALMRS(BLM's

Land Records system), and AUTOCAD formats. To transfer the files into ADS, a program must be run to create a file with Universal Transverse Mercator (UTM) coordinates. To create an ALMRS file, two programs must be run on a PGCF file. First, a program which creates a list of non-standard PCCS point identifiers that is used by a second program to create the ALMRS Point Identifier Translation file. All three interfaces are one-way. At the present time, AutoCAD, ADS or ALMRS files cannot be imported into the PCCS data base.

The interface to AutoCAD was utilized to accomplish WODDB using a grid generator built in to AutoCAD to construct the BLM ownership theme to the 1/16 corner level. The key point, however, is that the coordinate points generated in the PCCS program were used to geo-reference all of the data generated in the project. The data was then translated into MOSS (BLM's GIS software) for analysis purposes.

For the first time in the agency's GIS activities, the digital data is truly registered to the field located brass caps, to a surveyor's level of accuracy.

Future

The Bureau of Land Management is committed to developing a full Land Information System (LIS) to manage the lands under the agency's jurisdiction. Their definition of LIS is that it is composed of three parts: Resource Data; Land Records; and the National Geographic Coordinate Data Base(GCDB). They are collecting Resource Data as needed; collecting ALMRS records in digital format both in-house and by contract; and have let two contracts to Infotec Development, Inc. to abstract and process GCDB data for the continental U.S. and Alaska over the next four years. This data will be used by BLM to populate the National GCDB.

The final BLM GCDB will be the primary source for coordinate data for most GIS data bases, and as such, will contribute substantially to the quality of the data used for resource management. The first major effort to expand the use of the GCDB outside of BLM is now beginning in Oregon with a pilot project under the Northwest Land Information Systems Network. This project will involve two counties, Benton and Harney, in a data sharing and development process based on the GCDB developed in Oregon. The success of this project will probably lead to further work in the Oregon-Washington region.

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High Altitude Laser Profiling for Vertical Control in Small and Large Scale Mapping

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Abstract
Airborne Profile Recording systems for large and small scale mapping have now been replaced by laser technology combining integrated components which include bore-sighted standard cartographic cameras and small tracking cameras, precise altimetry and GPS positioning. McElhanney has recently completed a contract covering the islands of Kalimantan and Sulawesi in Indonesia providing vertical control and aerotriangulation for 1:50 000 map production. This contract required the installation of a high altitude laser system mounted onboard a fixed wing aircraft, to provide photo-identifiable vertical points which were transferred to mapping photography. The laser system, designed by Holometrix of Cambridge, Massachusetts, is the first privately owned high altitude unit to be integrated and designed specifically for such mapping applications. A total of 11 000 line kilometres were flown in four months over heavy jungle terrain providing true ground data to inaccessible areas. Project field operations, profile results and vertical transfer methodology are presented in this paper.

Introduction

Airborne profile recording (APR) for topographic surveys were first undertaken in the late 1940's with particular application in Canada to the vast northern wilderness areas. The early systems were timed radar measurements, using 1 1/2 meter diameter antennas and provided profile accuracies of approximately 10 meters. These systems were used extensively on projects throughout the world for map productions at small scales such as national 1:50 000 series.

Recently with the advent of laser technology, more accurate systems have been developed, and APR is being used not only in mapping applications, but also in hydrographic surveys, route profiling, forest inventory and water quality sensing.

McElhanney's development of an integrated laser system came from the Company's involvement in a large survey and mapping program in Indonesia. This program is being carried out as the Resource Evaluation Aerial Photography Project (REAP) and was designed to set up a physical and institutional capability in Indonesia to handle an accelerated program of natural resource development, particularly forestry, mining and oil and gas exploration. Canadian aid has sponsored the project over 3 phases commencing in 1979. Phase I was the establishment of horizontal and vertical control points using Doppler satellite observations to form a base for 1:50 000 mapping. This was completed by McElhanney in 1981 (A total of 238 stations established covering all of Kalimantan, Sulawesi and some of the southern islands). Phase 2 provided aerial photography coverage and Phase 3 has provided densification of vertical control using the laser APR, for aerotriangulation and numerical adjustment of the final map compilation.

The APR for use on Phase 3 was developed to provide high altitude terrain profile data at an economical cost using fixed wing aircraft. The system was developed for portability and to operate in relatively small aircraft with standard aerial camera ports. It is designed to acquire ground profiles for applications such as route profiling, cross-sectioning and vertical control for topographical mapping.

APR Profiling Principles

APR equipment when mounted and operated in an aircraft (airplane or helicopter) measures vertical profiles of terrain with respect to a reference isobaric surface.

The aircraft flies along a constant pressure altitude anywhere from 1 000 to 30 000 feet above the ground level. Pulses of laser energy (travelling at the speed of light, 186 230 mi/sec) are transmitted in a narrow beam and the elapsed time between transmission and return is a measure of the distance between the aircraft and the ground. These measurements are reproduced as a continuous line or profile of a narrow strip of ground traversed by the aircraft. A Barometric Reference Unit (BRU) senses deviations of the aircraft either up or down from a constant pressure level. The flight path of the aircraft is recorded by a tracking camera (70 mm frame or continuous strip camera), or other onboard navigation system.

After suitable adjustments to remove pitch, roll, BRU deviation and isobaric surface slope, and to adjust the terrain profile to ground datum, the profile is used to provide vertical control for mapping or other DEM applications.

The general method by which heights are obtained from profiles is as follows. The height of the reference isobaric surface must be determined at the start and end of the flight line by profiling over terrain of known height above the selected datum (i.e., sea level). The height of the reference isobaric surface over any unknown terrain point is interpolated from each end with respect to time. Knowing the aircraft to ground distance (from the laser range) over the unknown terrain point and the height of the reference isobaric surface, the height of a point on the terrain (APR point) may be calculated. By transferring selected points on the profile track from 70mm tracking film to the mapping photography, heights of APR points may be obtained on the mapping photography along the profile track or input by coordinates from an onboard navigation system.

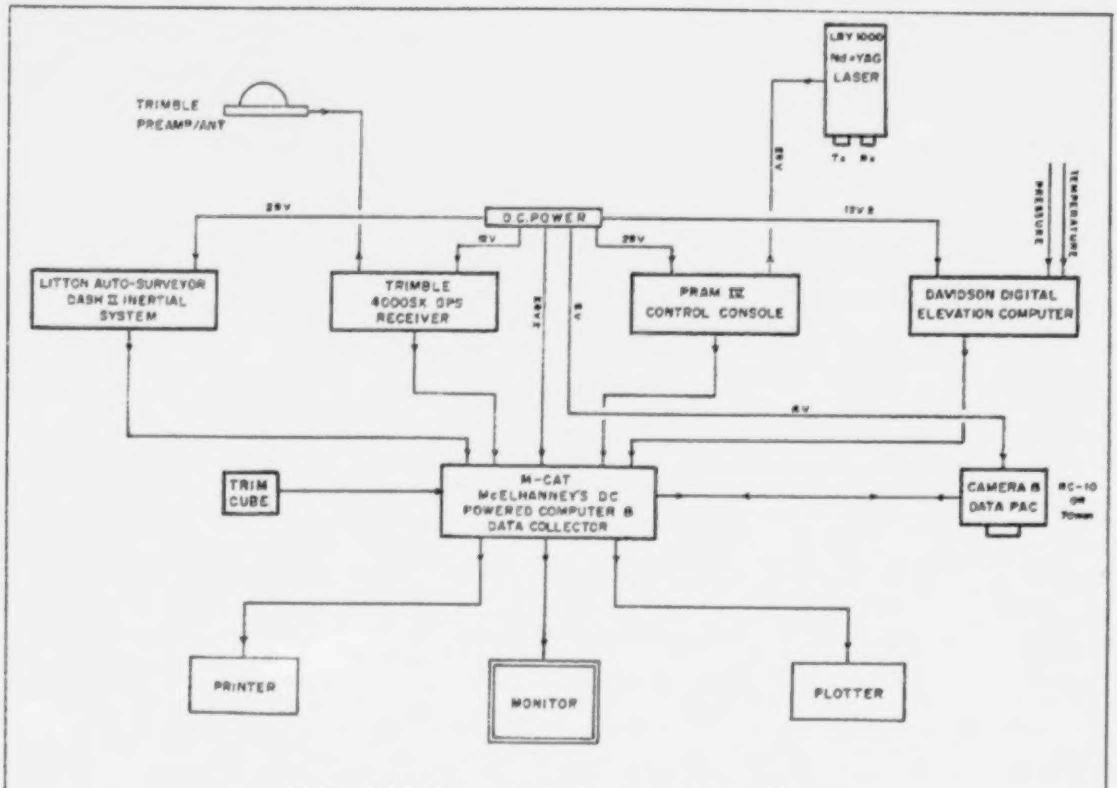
APR System Components

The McElhanney airborne laser system consists of five separate sensors, four of which are interfaced to the central processing unit and each drawing power from the central power distribution module. The system is essentially a passive data collector with the only control being over the tracking camera. The central computer waits for information from the altimeter, pitch/roll meter and the laser. It in turns triggers the tracking camera shutter and advances it based on operator inputs. It stamps all information coming in with a time tag, allowing it to later reassemble and correlate the data at the post processing stage. A description of each component is given below. Figure 1 illustrates the interfacing of the components.

Computer and Peripherals

The central processing unit for the laser system is the McElhanney designed M CAT.DC powered navigation computer which was originally developed for the Canadian Hydrographic Service for airborne and hydrographic survey applications.

The computer itself is composed of four major components. The processing unit is a PC - AT compatible mother board utilizing a 80286-10 high speed 16-bit microprocessor chip and a 80287 math co-processor chip. It has built into it three RS-232 serial ports and two parallel ports, which are used to integrate the survey sensors of the laser system. The M CAT's power supply is rated at 19-36 volts and is polarity protected allowing it to function in an airborne environment with minimal power concerns. The mass storage devices for the M CAT include a 20 Mbyte hardcard, a 1.2 Mbyte, 5.25 inch floppy drive and a 720 M byte, 3.5 inch micro-floppy drive. The system display monitor is an ASK LCD flat screen and graphics adaptor. The screen is lightweight and requires no power input other than the power drawn by the graphics adaptor card in the computer. The entire computer is designed to be rack mountable.


TRIMBLE
PREAMP/ANT
LRY 1000
Nd+YAG
LASER
Tx
Rx
28V
PRESSURE
TEMPERATURE
28V
D.C.POWER
12V
28V
12V 2
LITTON AUTO-SURVEYOR
DASH II INERTIAL
SYSTEM
TRIMBLE
4000SX GPS
RECEIVER
PRAM IV
CONTROL CONSOLE
DAVIDSON DIGITAL
ELEVATION COMPUTER
TRIM
CUBE
M-CAT
McELHANNEY'S DC
POWERED COMPUTER &
DATA COLLECTOR
CAMERA &
DATA PAC
RC-10
OR
70mm
PRINTER
MONITOR
PLOTTER

APR (MAPR) SCHEMATIC DIAGRAM

Figure 1

Laser Profiler
The laser used by the McElhanney system is the ACCI PRAM IV Model LRY-1000 pulsed laser, which was designed specifically for high altitude airborne service. It has a modular design consisting of a PRAM IV control console and a Litton NT-90 flash lamp-pumped Nd:YAG near-infrared laser transceiver. The transceiver utilizes side by side optics in a compact package designed for easy mounting in an aircraft. The separate control console is designed to be rack mountable. The laser has a peak power rating of 114 mjoules and can operate at speeds of 5, 10 and 20 pulses per second at ranges up to 6000 metres. Range accuracy of the laser is 0.1 meter. For the REAP III project the laser was always operated at 20 pps. As a safety precaution, the laser is fitted with filters to improve the eye-safe range to 400 metres.

Power to the laser transceiver is supplied directly from the aircraft, whereas, power to the PRAM IV console (28 VDC) is supplied via the McElhanney central power distribution unit. The PRAM IV profiler is interfaced to the M CAT computer via an RS-232 port. The PRAM IV profiler sends a steady stream of range and system status information at a rate of 20 ranges per second to the computer, which collects the data in a software-created ring-buffer.

Digital Elevation Computer
The laser system utilized a Davidson Elevation Computer Model D101 as a barometric pressure altitude reference. This solid state unit incorporates pressure and temperature sensors in a software controlled unit. The pressure sensor is maintained in a controlled temperature environment using an operator-controlled oven. The pressure sensor is connected to the aircraft's static system. Vertical resolution is 0.1 meter.

The D101 is built into McElhanney's DC power distribution unit and power (12 VDC) is supplied from the distribution module. The D101 is interfaced to the M CAT via an RS-232 port. The D101 measures the pressure once every 5 seconds and sends the pressure and temperature information to the computer.

Tracking Camera
The system's tracking camera is a Hasselblad 500 EL/M 70 mm format camera complete with an autowinder, a 50 mm super wide angle lens and a detachable 120 exposure film magazine. The film magazine is equipped with a built in DA-1 serial interface and a detachable DE-32 Datapac which allows the system to automatically annotate the 70 mm tracking film with data, time, roll number and frame number.

The camera is triggered via one of the central processing computer's parallel ports which sends a command to the McElhanney-built triggering device which translates the command into a triggering pulse which is in turn sent to the camera through the power winder power cable. Programming the DE-32 datapac for film annotation is accomplished from the computer via one of the serial ports and is normally done prior to the start of each line. The film utilized by the tracking camera is Kodak's 2402 Plus-X aerographic film. The frame interval was controlled by the central computer based on the operator selected ground speed, flying height and forward overlap. A forward overlap of 60 percent was used for the entire project.

Pitch and Roll Meter
The MDL TRIM Cube Model 40S provided pitch and roll information for the laser system. It is a two axis inclinometer using electrolytic gravity sensors with a single chip microcomputer used to demodulate the sensor information and produce a serial data stream. Roll and pitch information is sent to the central computer 5 times per second, where it is recorded with the other sensor information. The meter has a range of 40 degrees and a stationary accuracy of 0.25 degrees. In the airborne environment with its accompanying accelerations, the accuracy is severely decreased. Power to the TRIM cube (12V DC) is provided by the central power distribution module.

Power Distribution Module
The aircraft power (28V DC) is fed into the central power distribution unit, which then distributes it to the four survey sensors. Power at 28 volts DC is provided to the PRAM IV processing console, and the M CAT computer. The power supplied by the aircraft is further broken down to 12 volts DC and 6 volts DC. The 12 volt DC power is supplied to the digital elevation computer and the 6 volts DC is supplied to the tracking camera and datapac.

System Installation
The central processing unit, laser processing unit, digital elevation computer and power distribution module are all mounted in one rack. The remaining survey sensors, consisting of the laser, pitch and roll meter, and 70 mm tracking camera are mounted on a heavy duty aluminium alloy mounting base designed to fit into an RC10 standard camera mount. Figure 2 illustrates the mounting arrangement in the aircraft.

Large Format Camera
A large format camera was used during the REAP III project to supply supplemental photography. The Zeiss RMK A 8.5/23 camera complete with two magazines, 8.53 cm lens, drift sight and IRU were employed by the McElhanney system. The large format camera was not interfaced to the central computer system, although synchronization is possible using recorded times. Photography was captured with a forward overlap of 60 percent using Kodak 2405 Double-X Aerographic film.

Post Processing Peripherals
For post-processing the APR data, the M CAT computer is interfaced to a Okidata Microline 320 high-speed dot matrix graphics printer and to a Houston Instruments Hipad Plus Model 9012 digitizing tablet and cursor. The printer is interfaced to one of the M CAT's parallel ports while the digitizing table is interfaced to one of the computer's serial RS-232 ports.

Data Collection Software
Program MAPR V1.0 is used by the McElhanney system for the real-time collection of APR data. MAPR V1.0 was written by McElhanney in the C language and uses serial interrupts extensively to receive data from the survey sensors. The program is fully interactive and menu-driven, allowing the operator access to most levels of the program while the data collection is underway.

As data is read by the program, it tags the data with a time tag and then stores it in a unique device file on the hard disk. There is a file created for each of the devices, which include the laser, altimeter, camera and pitch/roll meter. The time tags allow the post processing section of the program to later reassemble the data and correlate it for adjustment and profile display.

The operator has several displays to choose from while operating in the real-time environment. The first display shows the status of all of the devices interfaced to the computer along with selected operator input parameters which control the camera exposure interval. Also displayed is time-to-exposure for the tracking camera and an estimate of the amount of film used by the tracking camera. A second display which can be seen simultaneously with the first shows some of the laser ranges, all of the altimeter readings and all of the tracking camera triggering pulses. Other displays include an error display showing all errors incurred by the system and a buffer display showing the status of internal software device buffers.

APR Data Processing
Post-processing of the data collected is accomplished using McElhanney-developed software packages designed to run on PC compatible computers. The following sections explain the concepts behind the profiling package and summarize the features.

The data acquisition system is essentially a passive data collector, exerting control over the tracking camera only. It tags all data coming into it with a time tag and then stores the data in a device specific file. For the REAP III project there were normally four files created containing the time tags in addition to: laser data; altitude data; frame centre data; pitch and roll data. The files are stored on floppy disk and accessed for adjustment and profile generation. All data collection, adjustment and profiling is performed with program MAPR V1.0. Processing flowchart is shown as Figure 3.

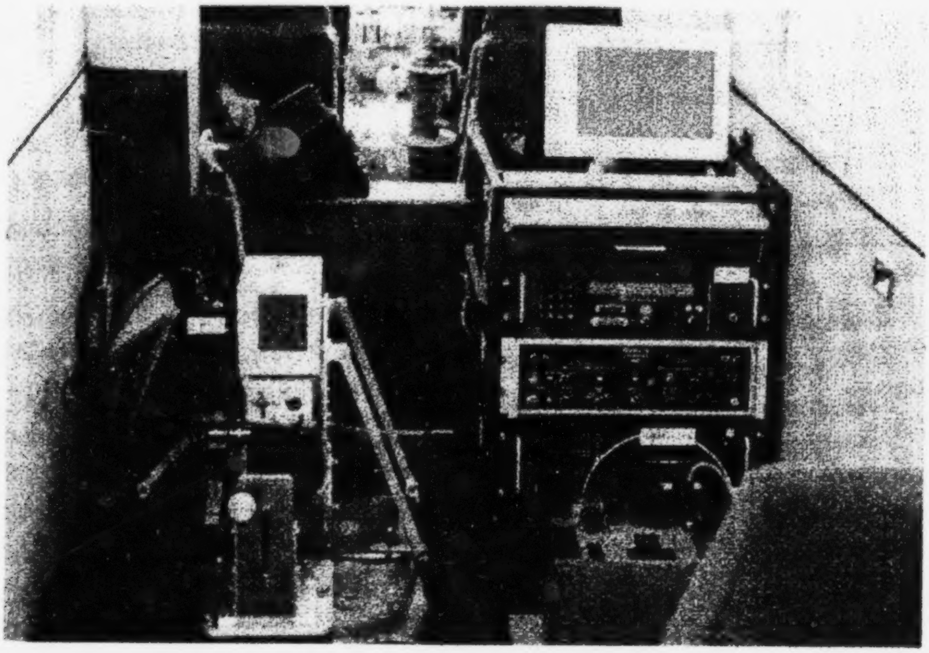


Figure 2

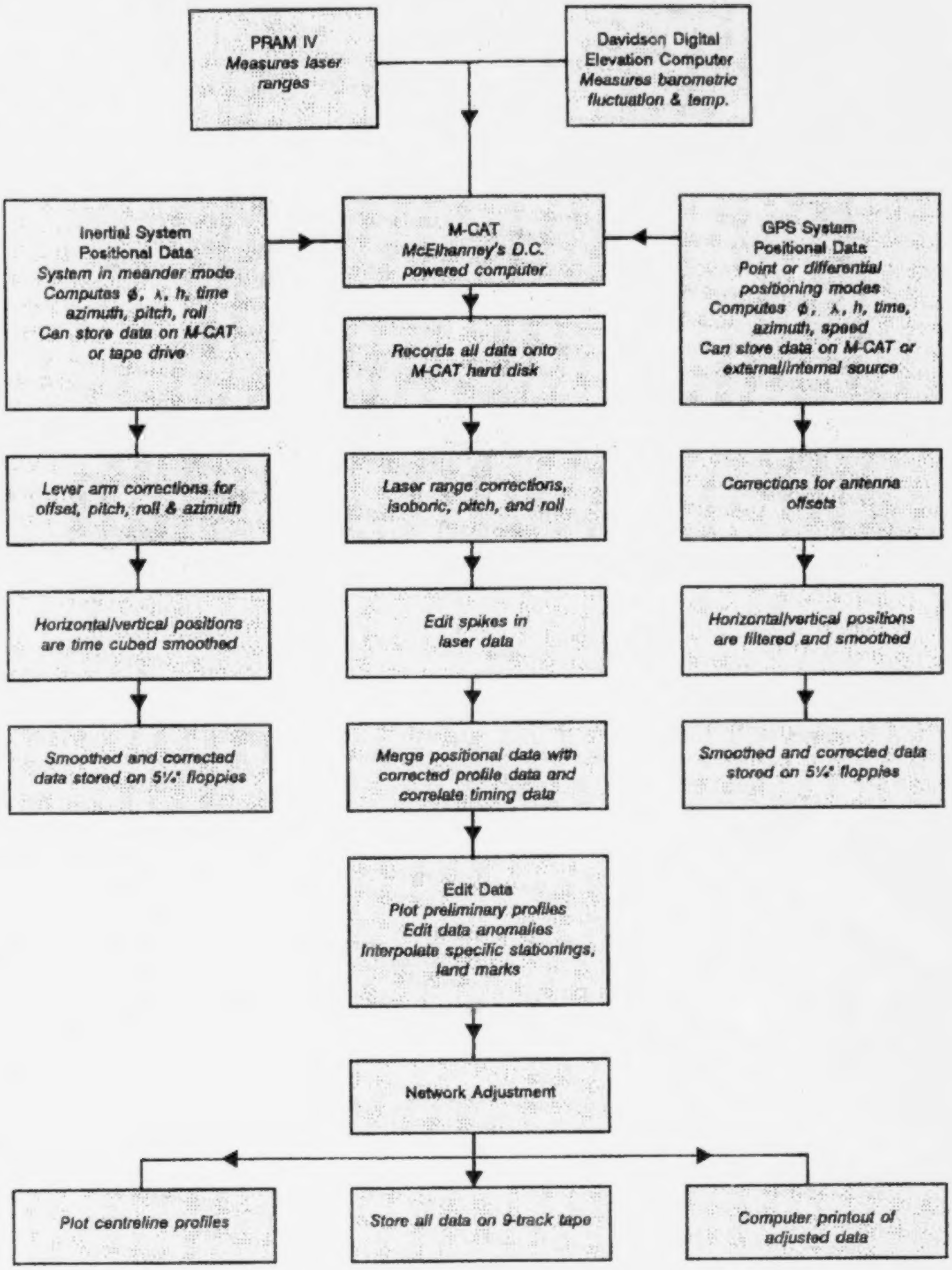
Examination of Profiles
At the end of each day's flying, all data collected was inspected for completeness. The data was processed through program MAPR and the unadjusted profiles were inspected for anomalies; poor laser tracking of water surfaces (necessary for profile adjustment); large gaps in data; improper exposure and firing of tracking camera. The data examination was typically completed within 24 hours.

APR Data Adjustment
The isobaric surface in the area of operations was quite stable, since it was close to the equator. This eliminated the need to apply an isobaric surface drift angle correction to the profiles. Instead, a linear correction was determined for each profile which corrected for the line's initial datum error and the elevation discrepancy at the end of the line. Two components were computed for each line using an adjustment routine resident in MAPR. The operator would inspect the unadjusted profile and input the time, raw elevation and the controlling elevation for the control points or sea level at the start of the line and end of the line or APR traverse. The program then automatically computes a translation component in metres which corrects for the line's initial datum error and a scaling component in metres per second which accounts for the residual discrepancy calculated at the end of the line or traverse. In addition, the operator can enter intermediate points into the adjustment and it will give misclosures for these points along with intermediate correction values. The operator is then free to interpret the results and enter the values most suitable as corrections for later profiling of the APR data. A printout of each profile adjustment is made and logged along with a graphical representation of the APR lines or traverses and the corrections. Corrections entered by the operator for each line, if satisfactory, were then saved in an initialization file which is stored for each line and can later be recalled when the data is to be inspected. This eliminates the need to re-enter the correction components and reduces the possibility of operator error.

Profile Display
The McElhanney APR data collected during the project was graphically displayed for interpretation using program MAPR. MAPR has a high degree of display flexibility permitted by the concept of time tagging. The display modes are summarized below.

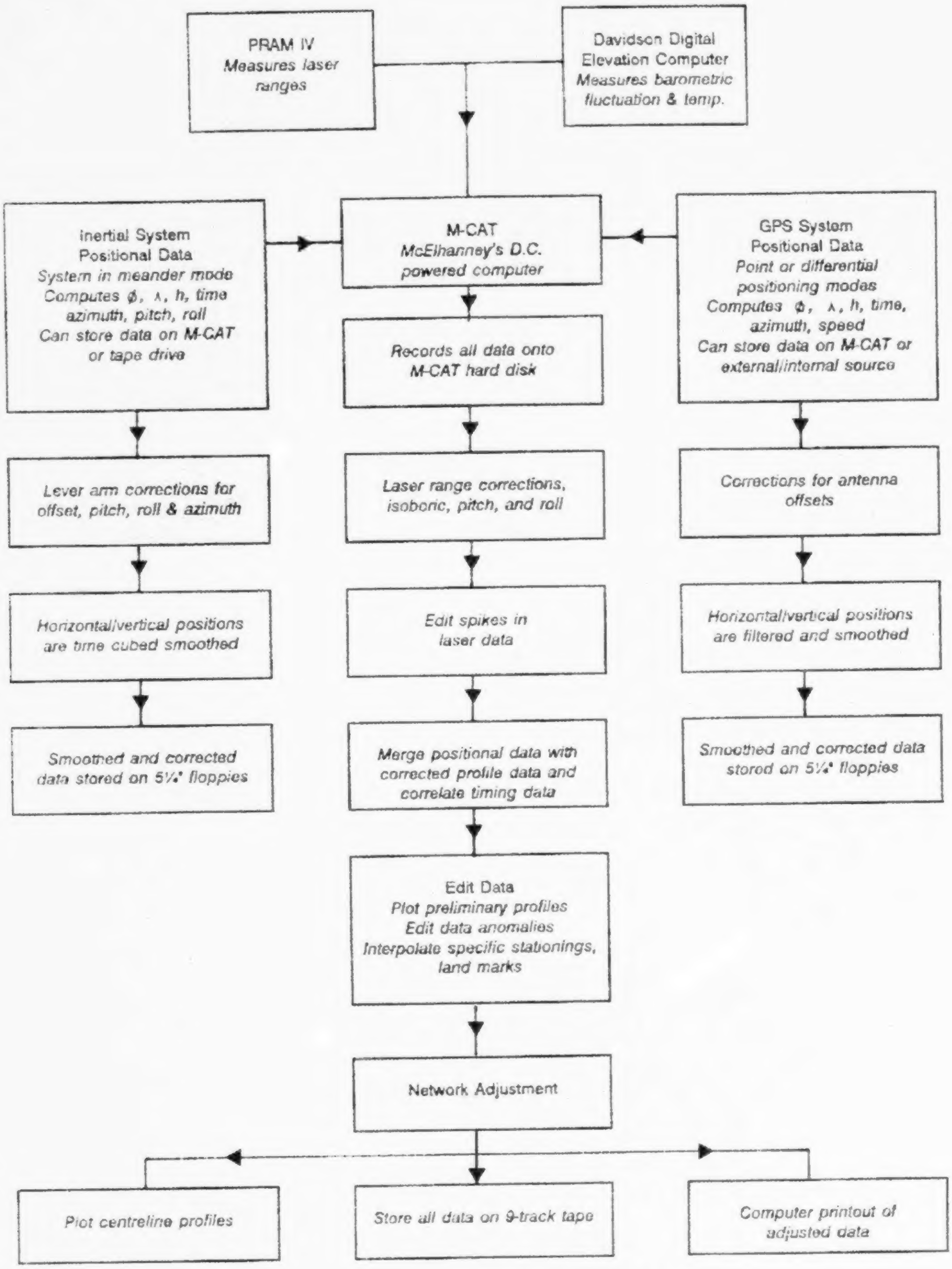
Display By Frame: Here the profile displayed is bounded on the horizontal axis by the centres of two of the tracking film frames. All profile information between the two frame centres is displayed. The user has the option to display the terrain, the aircraft's altitude or both in addition to the roll and pitch meter readings.

Display By Time: Here the profile displayed is bounded on the horizontal axis by two times selected by the operator. All APR data is displayed between these two times. This allows the operator to generate a profile with any horizontal scale.


PRAM IV
Measures laser ranges
Davidson Digital Elevation Computer
Measures barometric fluctuation & temp.
Inertial System
Positional Data
System in meander mode
Computes ϕ, λ, h, time
azimuth, pitch, roll
Can store data on M-CAT or tape drive
M-CAT
McElhanney's D.C. powered computer
GPS System
Positional Data
Point or differential positioning modes
Computes ϕ, λ, h, time, azimuth, speed
Can store data on M-CAT or external/internal source
Records all data onto M-CAT hard disk
Lever arm corrections for offset, pitch, roll & azimuth
Laser range corrections, isoboric, pitch, and roll
Corrections for antenna offsets
Horizontal/vertical positions are time cubed smoothed
Edit spikes in laser data
Horizontal/vertical positions are filtered and smoothed
Smoothed and corrected data stored on 5¼" floppies
Merge positional data with corrected profile data and correlate timing data
Smoothed and corrected data stored on 5¼" floppies
Edit Data
Plot preliminary profiles
Edit data anomalies
Interpolate specific stationings, land marks
Network Adjustment
Plot centreline profiles
Store all data on 9-track tape
Computer printout of adjusted data

APR (MAPR) PROCESSING FLOWCHART

Figure 3


PRAM IV
Measures laser ranges
Davidson Digital Elevation Computer
Measures barometric fluctuation & temp.
Inertial System
Positional Data
System in meander mode
Computes ϕ, λ, h, time azimuth, pitch, roll
Can store data on M-CAT or tape drive
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McElhanney's D.C. powered computer
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Positional Data
Point or differential positioning modes
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Horizontal/vertical positions are time cubed smoothed
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Smoothed and corrected data stored on 5¼" floppies
Edit Data
Plot preliminary profiles
Edit data anomalies
Interpolate specific stationings, land marks
Network Adjustment
Plot centreline profiles
Store all data on 9-track tape
Computer printout of adjusted data

APR (MAPR) PROCESSING FLOWCHART

Figure 3

Table 1. Summary Of Linear Adjustment Data And Corrections For MAPR - McElhanney Aerial Profile Recorder - K1 Block - REAP III

October 12, 1989

Line	Correct Elev (m)	Observed Elev (m)	Time (hh:mm:ss)	Translation (m)	Scale (m/s)	Misclosure (m)
116V6	0.7	0.6	08:18:56.98			
	0.3	-0.3	09:42:32.83	0.1	0.00010	0.5
116_SL	0.0	23.0	08:05:49.95			
	0.0	21.0	09:36:20.5	-23.0	0.00037	2.0
116V5	2.0	7.8	08:16:22.25			
	0.0	4.2	10:18:55.79	-5.8	0.00022	1.6
116V6	0.7	0.6	08:18:56.98			
	0.3	-0.3	09:42:32.83	0.1	0.00010	0.5
116_SL	0.0	23.0	08:05:49.95			
	0.0	21.0	09:36:20.5	-23.0	0.00037	2.0
116_SL2	0.0	23.0	08:05:49.95			
	0.0	21.0	09:36:20.5	-23.0	0.00037	2.0
117V2	1.5	13.9	09:41:54.54			
	0.5	13.5	10:23:17.23	-12.4	-0.00024	-0.6
117_SL	1.5	13.9	09:41:54.54			
	0.5	13.5	10:23:17.23	-12.4	-0.00024	-0.6
118V1	0.0	-1.0	08:43:15.00			
	0.0	-1.1	09:49:46.50	1.0	0.00003	0.1
118V2	0.0	-7.3	07:55:21.00			
	0.0	-8.5	09:13:42.00	7.3	0.00026	1.2
118V3	17.2	32.4	09:19:42.71			
	1.5	13.9	09:41:54.54	-15.2	0.00210	2.8

When a profile is created, MAPR correlates the laser, altimeter, pitch and roll readings as well as the frame centres using their time tags. Since the system records some 100 laser pulse within the 5 seconds update time of the digital elevation computer, the program does a straight line interpolation of the altimeter data based on the time of each laser pulse.

An operator-controlled filter helps eliminate spurious data within the profiles. An indicator at the top of the profile shows where data has been rejected.

To facilitate point selection along the profile the program utilizes a digitizing tablet and cursor. The operator digitizes a left and right photocentre on the tracking film, after which he can digitally display elevations, altitude, roll and pitch along the profile as the cursor is moved within the tracking film. This, coupled with the stereo images on the tracking film, allows the operator to identify features and transfer them to the mapping photography for mensuration. Selected points were also entered automatically into a log file by pressing one of the cursor keys.

Printouts of the profiles are available using a high-speed dot matrix printer. The operator has the option to print one profile only or the entire line (at any scale). Figure 4 is a reduced copy of a printout.

APR Project Application

The Indonesian project provided a real test for both hardware and system capability. Terrain in Kalimantan and Sulawesi varied from low level swamps and jungles to densely forested mountains, with temperatures consistently in the low 30's and high humidity. Elevation varied from sea level to more than 3000m.

Field base camps at air strips were established throughout the project area and general transportation was either by aircraft or boat due to the lack of roads.

Weather was the major contributing factor in profile production. Generally, flight missions were achieved during the morning before any cloud build-up developed. Extreme heat, haze and cloud affects laser penetration and restricts identification on aerial photography.

Flight profile lines were chosen to meet mapping specifications for vertical point density and also to follow the geography of the land so that major features such as mountain ranges, rivers, lakes and coastal areas were easily identifiable. Daily flight planning was critical to ensure planned flight paths were covered and profile gaps were fully completed.

Profile lines commenced and terminated on points of known elevation such as sea level, lakes, rivers or large open areas. Additional check and common points were tied in along the flight path to improve closure accuracy and detect any blunders. After each day's mission, all profiles were verified and adjusted prior to the next day's mission planning.

Profile data and aerial photography were forwarded to photogrammetrists based in Jakarta. Here, the vertical point selection, identification on the 70mm film and transfer to the mapping photo was completed. The results were processed through the aerotriangulation adjustment program PATM which verified the elevation value with the identified point selected.

Profile Results
Flight missions were run from a half hour to 8 hours per day (averaging 3 hours over the project) depending on the weather conditions. A sample printout of line closures is shown in Figure 4.

The misclosure of the flight line is calculated on a meter per second basis for the total flight mission, and applied to the laser ranges on a linear time basis.

Elevation closures were 0.5 m to 2.0 m depending on the flight time, which relates to a 2 to 6 cm vertical correction per kilometre.

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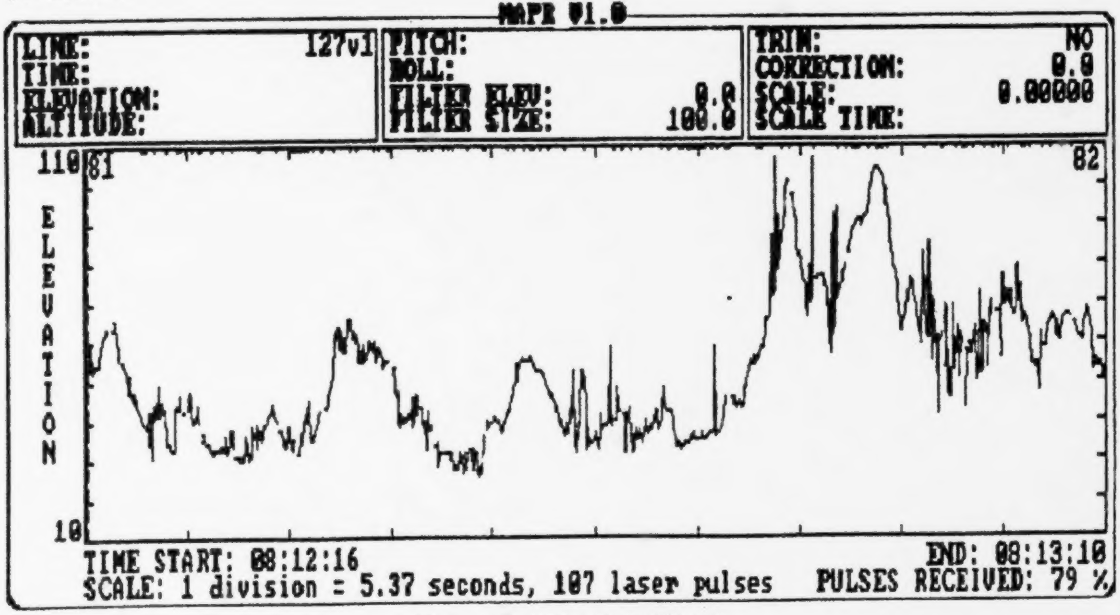

```
MAPR V1.0
LINE:            127v1   PITCH:                 TRIM:              NO
TIME:                    ROLL:                  CORRECTION:       0.0
ELEVATION:               FILTER ELEV:     0.0   SCALE:        0.00000
ALTITUDE:                FILTER SIZE:   100.0   SCALE TIME:

TIME START: 08:12:16                                   END: 08:13:10
SCALE: 1 division = 5.37 seconds, 107 laser pulses   PULSES RECEIVED: 79 %
```

Figure 4. Real Time Profile Printout

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An Introduction to the Global Positioning System and Its Use in Ground Truthing Spot Satellite Imagery

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Abstract

The NAVSTAR Global Positioning System (GPS) provides accurate position data which can be used to aid the users of satellite imagery and other remote sensed data. When fully deployed, GPS will use 24 NAVSTAR satellites in a constellation arranged to provide 24-hour coverage with 3-dimensional position fixes accurate to better than 25 meters. In differential mode, the accuracy will be better than 5 meters. For high accuracy survey applications, the errors will be in the millimeter range. The GIS applications of GPS include first geo-referencing satellite imagery and then using the GPS receiver to navigate to a site for ground truthing the satellite image. A case study is presented where SPOT imagery and GPS ground truth data were integrated using GRASS Software.

In this case study from the Everglades National Park, GPS was used for a research project studying how plant cover in the slash pine forests of the Everglades affects fire management practices. Using GRASS to display and classify a SPOT image, 16 classes of different spectral reflectance were identified. The image was geo-referenced using both USGS quadrangle sheets and a data logging GPS receiver. Excellent results were obtained from each geo-referencing method. The value of GPS became apparent when it was used to navigate to 30 randomly selected ground truth sites. These sites were quickly and easily found and the ground truthing was completed in a very short time. With GPS it was possible to find a site more than 1.5 km from the nearest road through thick underbrush and then travel to four more sites each 0.8 km from the next with complete confidence that the correct site had been located. Navigation in the Everglades pine forest without GPS would have been very difficult.

Introduction

In a project designed to investigate the uses of Global Positioning System (GPS) in Everglades National Park, we conducted a number of tests. These included position data collection, comparison of GPS position data to position data digitized from 7 1/2' topographic maps, and geo-rectification of SPOT imagery using GPS position data. Applications of GPS in Everglades National Park include geo-rectification of remotely sensed imagery, acquisition of position fixes of study sites in remote wilderness, and rapid mapping of long, convoluted plant community and fire boundaries. The liaison between GPS, GRASS, a Geographic Information System, and remotely sensed digital data can enhance the research and resource management activities within a large wilderness, such as the Everglades National Park.

In this study, GPS PATHFINDER™ data recording receivers were used. GPS PATHFINDER receivers allow direct digital data entry, are portable and are easy to use. This ease of use will allow GIS data bases to be created and maintained by users with little knowledge of traditional surveying and mapping techniques.

GPS PATHFINDER is a trademark of Trimble Navigation, Ltd.

Introduction to GPS

When fully deployed, GPS will provide world-wide, 24-hour, 3- dimensional continuous position fixes, accurate to within tens of meters. This system is paid for by the US taxpayer through the US Defense Department. With the current partial coverage and the prospects for 24-hour coverage in a few years, GPS is a viable tool for all concerned with maintaining or creating a GIS data base.

Global Positioning System

A total of 24 GPS satellites are planned, including 3 in-orbit spares, in 6 orbital planes. The orbital period for all the satellites is approximately 12 hours, with an altitude of about 12 000 miles. Each satellite contains a very accurate cesium or rubidium clock which is synchronized to all the others and to the ground control stations. The satellites radiate spread-spectrum coded signals which are received by the user's GPS receiver. Along with timing information, each satellite transmits information allowing computation of the satellite's exact position. The GPS receiver decodes the timing signals from the satellites in view (4 or more), and knowing their location, computes a latitude, longitude, altitude, and time. This is a continuous process and generally the position is updated on a second-by-second basis on the receiver's display.

Current GPS Constellation

The current (January 1990) GPS satellite constellation has eleven satellites. This constellation provides approximately eight hours of 3-D positional fixes per day in North America. Coverage in other parts of the world will vary. The daily observation window appears approximately 4 minutes earlier each day. In the summertime in North America, the current constellation of satellites is visible during daylight hours. In the wintertime, the constellation is visible in North America during the night. As more satellites are launched at the planned 60- to 90- day intervals, these coverage windows will expand until a full 24-hour coverage is available in 2 years.

Older Technologies Being Replaced

The Global Positioning System will eventually replace two current navigation systems, LORAN and TRANSIT. LORAN is a ground based navigation system providing continuous positional fixes accurate to about 500 feet in coastal waters within range of a LORAN chain. The TRANSIT system provides worldwide coverage but only 10 to 30 fixes per day. Sub-meter accuracy is available after 2 days of observation by a stationary user.

Selective Availability and Differential GPS

The autonomous accuracy of positional fixes depends mostly on the actions of the Defense Department and how much they will degrade performance for civilian users. This degradation process is called Selective Availability (SA). When SA is enabled, the position fixes may wander up to 100 meters from the true position. To get a good position fix in the presence of SA, differential GPS is used. With differential GPS, a reference GPS receiver is set up on a known location and any deviations from 'truth' are used to correct the locations computed by another GPS receiver at an unknown location. Systems are available to do this differential processing either in real-time or as a post-processing operation. With differential GPS, accuracy will be on the order of 1 to 5 meters.

If better accuracy is desired, survey grade receivers are available. These receivers are specified to have an accuracy of 1 centimeter + 1 millimeter for each kilometer of baseline. For example, two survey grade receivers separated by 10 km will compute a separation of 10 km ± 2 cm. Survey grade receivers only work in differential mode.

GIS Data Base Benefit of GPS

One of the greatest advantages of GPS for GIS applications is that the data is collected quickly and accurately with a common reference system. With data logging GPS receivers, the coordinates, time, and other attribute information may be collected and then exported to a GIS data base with no manual digitizing operation. Since GPS provides a common reference system, data from GPS sources and sources rectified with GPS will register with each other and with GPS data collected in the field.

GPS Data Recording Receiver

An example of a GPS receiver specifically designed for GIS applications is the Trimble Navigation, Ltd., GPS PATHFINDER system. The GPS PATHFINDER system has a portable, data recording, battery powered GPS receiver for field use and a suite of post-processing programs specifically designed for GIS applications. The most important post-processing function is the ability to export differentially corrected positional data in a desired GIS data format including ARC/INFO, GRASS, AutoCAD DXF, MOSS, GeoSQL, EPPL7 and ERDAS.

GPS PATHFINDER Operation

While in the field the user can perform a variety of navigation and logging functions. For example, to map the boundary of a field the user would travel to the starting point, turn on the receiver, verify that positional fixes were being generated by observing the display, and turn on the data logger to start collecting a data file. Then all that is necessary is to walk, drive or fly around the boundary to be digitized. At the end of the path, the data logger is turned off. Upon returning to the office, the data logger is connected to a PC and the files are extracted and the position data is converted to the desired GIS data import format of your choice. The post-processing software allows reviewing and plotting on 1:24 000, or any other scale, overlays using a HPGL compatible pen plotter.

Using Differential GPS

The GPS data files may be made even more accurate by using differential GPS. In differential GPS, one GPS PATHFINDER receiver is set on a known location and set to record a reference file. This reference file will allow the generation of a time-tagged position correction that can be applied to a remote GPS data file collected within a few hundred miles of the reference location. Using differential GPS , and averaging for three minutes at a stationary point reduces the standard deviation of the error for a point location to less than 2 meters. Laser tracking of a moving vehicle indicates the accuracy of dynamic differential position data will be in the 5 meter range.

Geo-Rectifying a Spot image with the GPS Pathfinder Method

During the nights of 12-14 March 1989, a Trimble Navigation GPS PATHFINDER data logging receiver was used to map features such as hydrologic gauging stations, benchmarks, roads, and plant community boundaries within a south Florida Slash Pine ecosystem approximately 28 000 hectares in area. The GPS position data was converted to a GRASS 3.0 sites format in UTM coordinates, registered to the NAD-27 datum. The four corners of the USGS quad were registered. The residual error for the registration was no more than 3.0 meters. Next, sixteen geo-rectification points on the quad were located and digitized for analysis using a Paired Sample T-test. Digitized point locations from the quad were used to geo-rectify the SPOT image for a comparison to the GPS data. The final scene geo-rectification was done using the GPS position data and the GRASS i.rectify module. The landcover cell file generated was transferred to a GRASS-GRID Mapset for additional use. The GPS site data was then overlaid on the landcover cell file.

Results and Discussion

The results of the comparison of orthophoto quad (residual mean square error = 0.71) versus GPS (residual mean square error = 0.82) point data for geo-rectification reveals little difference between the two methods. Either error is acceptable for the geo-rectification of SPOT satellite imagery. A direct comparison of GPS data to quad sheet data reveals little difference between the UTM Eastings and Northings. However, a paired Sample t-Test showed a significant difference between the Northings: Mean 7.02 m, std. dev. = 8.70 m, t-value = 3.23, p = 0.006. No significant difference was found between Eastings: Mean = 4.44 m, std. dev. = 18.65, t-value = 0.95, p = 0.356. Although there is a significant difference between Northings and a relatively large standard deviation for the Eastings, these differences are within the error one would expect from digitizing an orthophotoquad of scale 1:24 000. At this scale, the width of the crosshairs relative to the ground is about 20 meters.

Ground Truthing Randomly Selected Points

After rectifying the SPOT image, the accuracy of the pixel classification was checked by ground truthing 30 randomly chosen locations. The 30 locations were selected using a random number generator and covered most of the different communities represented in the Long Pine Key study area. The coordinates of the 30 points were converted from NAD-27 UTM coordinates into WGS-84 latitude-longitude positions using the same transformation values originally used to convert from WGS-84 into NAD-27 for the geo-rectification. These positions were used as destination waypoints in the GPS PATHFINDER System. For each destination waypoint, the desired waypoint was navigated to using the real-time navigation display of the GPS set, which shows distance and direction information. A typical point would be 700 meters from the previous point. The pine tree canopy caused a bit of noise in the instantaneous positional fix, however, this was only a problem when we were within about 20 meters of the target. At greater distances, the bearing to the destination was relatively constant. We could tell when we were at the destination point when the bearing started to jump around and the range to the destination was less than 20 feet. At each destination, the vegetation cover was observed and recorded in a field notebook. This information included the density of the canopy, the density of the ground shrubs and the state of the ground cover, since these three different vegetation categories affected the SPOT image classification.

Conclusion

The results of these tests support the use of GPS navigation grade receivers to gather position data for the geo-rectification and ground truthing of satellite imagery. GPS is an operational system that will benefit the users of GIS data bases in collecting accurate geographic coordinates for creating, updating or maintaining their own GIS data bases. Portable data-logging GPS receivers will be especially useful in wilderness areas that have few human cultural features and landforms that appear on satellite imagery but do not appear on orthophotoquad maps.

Data Issues and Remote Sensing

Session F3
Data Structures

A Method of Accessing Large Spatial Databases

Data Structures for GIS

An Efficient Data Structure for Surface Analysis in Vector-based GIS

A Comparison of Partitioned and Seamless Organizations of Spatial Data

GIS'90 Symposium

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A Method of Accessing Large Spatial Databases

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Abstract

The explosive growth of GIS technology in the past few years has resulted in production of massive amounts of digital spatial data. When this data is to be used in a coherent regional or state-wide LIS consisting of multiple thematic layers of continuous coverage, accessing specific entities such as an ownership parcel in a timely manner is a common function that demands efficient algorithms. The requirement for efficient spatial searching is recognized as an important GIS topic by The National Center for Geographic Information and Analysis. The National Center has identified development of methods for effectively structuring spatial search algorithms as Objective Two of Research Initiative Six.

In addition to efficient spatial searching, coordinate precision cannot be compromised in these databases nor can project bounds always be set prior to database construction. As different thematic layers require different map resolution, the same coverage may even require different resolutions due to the density of data. Added to this is the requirement to maintain permanent and temporary views of a partitioned database as a continuous database.

This paper describes methods which use RDBMS and conventional non-DBMS technology for searching and manipulating large spatial databases. The method for sending information to and receiving information from a RDBMS or corporate database is also described.

This method is currently in production use in cities, counties, multi-county regional areas, and statewide areas. The method has been developed by a team of GIS software engineers and fielded in the last revision of a commercial GIS.

Introduction

The requirements for geographic information systems are increasing rapidly. Users are expecting efficient handling of large volumes of data. Additionally they require the system to operate in a continuous or seamless manner. "They simply want to type 'PLOT SOILS'" (Reed 1988) and see all soils maps without knowledge of the component map sheets or files.

Generally, spatial database performance depends on the number of disk accesses needed to retrieve data. Disk access is expensive and performance improvements can be achieved by reducing the number of disk accesses through buffering and indexing the storage elements (Egenhofer 1987).

In today's environment of rapid cpu performance increases but slow disk access speed increases, configuring a system whereby the number of disk accesses is minimized leads to a responsive system. The key to efficient accessing of large spatial databases then is to minimize disk access.

Obviously, even a single thematic layer, such as the 3 000 000 land ownership parcels in New South Wales, Australia, cannot be loaded into memory at system initialization time and processed thereafter. While this would minimize disk access to one access for each byte of data, memory prices and the need for concurrent processing of several thematic layers prohibit this approach. A method of indexing and partitioning the database to the users spatial area and theme of interest must be used.

Use A DBMS

Ideally, the solution to efficient access of spatial data lies in currently available DBMS technology. Modern DBMS are fast, offer a variety of indexing methods and handle large databases. However, standard database management systems do not fill this role regarding spatial data. Performance is unacceptable and appropriate data structuring is missing (Egenhofer 1987). Spatial data cannot be properly handled as strings, reals, and integers in a table format. In addition, methods for 'long transactions' are simply not in place in modern DBMS to handle spatial transactions (Dangermond 1989).

Time tests using a DBMS for spatial data on mainframe and supermini-computers can not even match the speeds of a 386-PC. Prototyping of a GIS using a DBMS was quickly abandoned. Typical spatial queries involve comparison of spatial extent with a minimum bounding rectangle. Even this simple operation for a GIS cannot be accomplished efficiently in a generalized DBMS.

In short, at this time, the indexing methods of commercially available DBMS cannot accommodate the needs of spatial data. Even though a DBMS cannot accommodate spatial data as yet another field in a thematic database, they are very adept at handling tabular data structures such as demographic data. This has led to the use of a DBMS in conjunction with a GIS to combine spatial and tabular processing in what has been termed 'Geo-Relational' or 'Hybrid' data models (Morehouse 1985). This is the only practical way for GIS practitioners to handle spatial data unless the goal is to become tabular data experts instead of spatial data experts.

What to Do?

For efficient spatial processing, the solution lies in keeping data that is needed together in close proximity on disk. This can be achieved by computing a spatial index value that combines X- and Y- coordinates as the key indexing field and passing this to a DBMS. The problem is that as map features are added and removed from a map, the DBMS becomes fragmented and data that is needed in one spatial view is in different locations on disk causing loss of efficiency. Even vendors of the most commercially successful DBMS recommend dumping the database to a flat file and reloading on occasion to increase performance.

The file systems of modern operating systems are very adept at keeping blocks of data in readily accessible units. The cost of retrieving a large number of bytes is not much greater than retrieving a small number of bytes once the disk head is in the proper position. If a DBMS cannot efficiently access spatial data, why not use the inherent characteristics of the file system for spatial data instead of all the indexing methods of an expensive DBMS that do not operate effectively on spatial data?

Keep It Simple

Most modern file systems provide for a hierarchical directory structure. The no-cost directory structure provides for efficient access of a multitude of files.

When designing spatial access algorithms, something as generalized as a DBMS is not going to be as efficient for accessing fields of information as static as the structures in a GIS. DBMS are designed for adding fields. A GIS has fixed fields of spatial information and there is seldom a need to add fields to the structures once the system is in production mode.

If commercially available software such as a DBMS cannot provide an efficient method of accessing large spatial databases, customized software must be developed. This software must, however, use proven algorithms that have been researched in the literature and implemented to illustrate effectiveness. To shorten the development cycle and take advantage of other organizations contributions, standard software should also be employed.

The method described in this paper does, for a large part, accomplish the above stated goals. It relies on software such as the UNIX file system that other organizations are enhancing as well as readily available software such as B-tree indexing.

The Implementation

Users are comfortable with the concept of spatial data in layers of information such as soils, hydrology, or parcels. This approach has obvious advantages as pointed out in what has been described as a geo-relational approach as opposed to a feature- oriented approach (Dueker 1985). Building 'smart software' instead of 'smart databases' has obvious advantages of future flexibility for constructing new approaches to problems and discovering new application needs of spatial data (Dangermond 1989).

Users are also accustomed to separating data into spatial units. Why should data from one disparate place on the earth logically be stored with data from another widely-displaced position?

Using the ideas of thematic coverage and spatial location can be combined with the familiar DBMS concepts of databases or tables. Although loosely defined, the implementation of databases does not preclude mixing different thematic layers and spatial locations. It simply defines a mechanism whereby users can pigeonhole data. Other groupings can be used instead of groupings by thematic content or spatial location and might include precision, resolution, age, scale, or classification. Whatever the grouping, from the users point of view the operation is to 'OPEN DATABASE ABC'. The implementation from a software view is to provide access to a directory of mapped data.

A great deal of access efficiency is achieved very easily using this simple mechanism of separating maps into databases in directories. Only currently open databases are examined allowing the system to ignore large sections of disk.

This approach has at least one distinct advantage, other than efficiency, which can be gained through the methods subsequently described. Access and update control can be assigned to the databases, whether they are spatially, thematically, or otherwise organized. Passwords for read and write access or even operating system access control can be set such that only planners update zoning information and only engineers update water lines, but all users can access parcel boundaries in the cadastral layer.

In the implementation, databases are flexibly defined according to the organization's needs. Read and write passwords are allowed to accommodate access and update. The mechanism also allows for sensitive data such as police information to be under the total control of an individual or department. When read passwords are assigned, data cannot even be accessed unless the password is known. This can also be reinforced by operating system access control for read and write privileges.

Once the database has been established into thematic or spatial groups that can be opened, a method of quickly performing spatial and thematic data searching is required. The method used for locating spatial data incorporates R-tree algorithms (Guttman 1984). The method used for locating thematic data is via B-tree algorithms.

R-trees provide extremely rapid searching of minimum bounding rectangles(MBR). The MBR of each map in the database is loaded to the R-tree index. When a spatial query of the database is conducted, such as "What data is in my current viewing window?" or "What data is at this point?", the R-tree index is searched.

B-trees provide extremely rapid searching of thematic attribute information. The primary attribute of a map feature such as the parcel ID of an ownership parcel is loaded to the B-tree index. When a thematic query is conducted, such as "Retrieve parcel XYZ789", the B-tree is searched.

When a database is constructed, maps can be added to an index map that incorporates R-trees and B-trees. An index map is a map of maps and serve in a sense as a map library. A database typically has one index map but this convention is loosely defined and users are free to construct index maps according to a variety of criteria such as precision, resolution, scale, age, etc. to further dissect a database.

However, there are strict requirements when constructing index maps to provide for a continuous map database. All maps in an index must be in the same map projection and maps must not overlap. Using only these two conditions allows for access of spatial data in a continuous manner as described later in this paper. The map projection must be the same since continuous processing is impossible without use of the same coordinate system. Non-overlapping maps are required for the obvious reason that an overlapping area is not continuous.

Other restrictions that are typical in other GIS are not enforced. No predetermined project extent is established for an index map. The spatial extent of an index map expands as maps are added to it and contracts when maps are removed. Map sheets can be rectangles of any size. No tiling takes place. This allows for smaller spatial extent maps in areas of dense data, such as a city center, as opposed to the periphery of an urban area. Empty tiles do not need to be created for areas that are not yet mapped. No tile size has to be pre-selected, areas of denser data can be in smaller spatial extents so that unnecessary overhead in file processing is avoided in dense areas. No loss of precision takes place. Each map in an index is stored with its own local offset and precision. In addition, a map is the exact same disk file whether or not it has been added to an index map.

Users can construct a database using a map series typical of paper map coverage. Although users require a modern GIS to operate in a continuous manner, they often request and are more comfortable knowing that the familiar old map sheet XYZMAP or a quad sheet named WOLFRIDGE is still around as a distinct entity. Index maps and the method used do not, however, preclude chopping the spatial coverage into arbitrary rectangles of a fixed size or conglomerating tiles into larger rectangles.

Using R-tree and B-tree algorithms that are proven technology provides a simple but very efficient mechanism for quickly locating a map in a database. Spatial searches are conducted by comparing the MBR of interest to the R-tree. A list of pointers to map partition names is returned. Using the open database name, a direct path-name is constructed to the spatial data of interest.

In addition, the MBR of interest is first compared to the MBR of the index map before the R-tree of the index is even searched. Speeds available in an R-tree search do not noticeably deteriorate as database size increases since tree re-balancing takes place as rectangles are added and removed from the tree. Response times are approximately one second of clock time for a search of 5000 MBR on a UNIX based workstation such as an HP-370.

All input values are converted to longitude/latitude pairs and MBR in the R-tree are stored as integers. Precision is quite acceptable since .000001 of a degree of precision is stored. All computational operations can then be performed in integer arithmetic which is much faster than floating point. This avoids the need of double precision coordinate storage to maintain map accuracy standards and it also saves disk space by storing thirty-two bit integers instead of sixty-four bit double precision values.

Using a B-tree for thematic search is also very efficient. A primary key is input and compared to the keys in the B-tree index. A list of pointers to map partition names and pointers to features in the map are returned. As a result, a query such as 'SHOW ME PARCEL XYZ789' can be accommodated in an extremely rapid manner since a direct pointer to the database/map/feature ID is returned. Response times are approximately those of R-trees.

Use of B-trees in an index map is also advantageous in the geo-relational approach where thematic data is stored in a DBMS. After queries are conducted in the DBMS, a common key such as a parcel ID that is the primary key in both the DBMS and the GIS, can be sent from the DBMS to the GIS. The GIS uses the B-tree of the index map and returns not only the map file name but a direct pointer to the feature. This provides for extremely rapid response in thematic/spatial or DBMS/GIS interactions. Similarly, the common key can be sent from the GIS to the DBMS where the DBMS provides its own mechanism for indexing tabular data, performing operations such as relational joins, and forms presentation.

As a side issue, the implementation is not hard-coded to a particular DBMS. Oracle, Ingres, Informix, and HPSQL have all been used. In addition, databases on different machines with different operating systems have been used by transmitting ASCII files of common keys. As a result, existing tabular databases in the DBMS and the computer of the user's choice can continue to be used. There is no need for a particular DBMS of the GIS vendor's choice to be forced on the user or to do something as inefficient, limiting, and wasteful as to use one DBMS to access another DBMS.

In addition, index maps of different thematic layers can be used together with no requirements for matching sheet sizes between indexes or even matching map projections. Also, different map data types, such as text annotation and raster maps, can be added to an index map for rapid spatial searching.

Accessing Data in an Individual Map

Use of B-trees provides direct references to a feature in a map. This is suitable for efficient access of large databases when the search is a thematic search of the primary feature attribute or common key.

Use of R-trees provides quick reference to the map partitions of interest when the search is a spatial search with an MBR. However, if the map partition contains a large amount of data, such as 20 000 soils polygons, additional methods including fast indexing must be used on the data in the map partition itself to limit disk access.

This is accomplished by several methods. The most obvious and a common method used by popular GIS is segmentation of the map data into tables of information for features, arcs, nodes, primary attributes, etc. This groups data and instills normalization into a dataset. Processing algorithms take advantage of the tables by using the most appropriate table, ignoring the data in the other tables.

Disk buffering in the application program is also used to reduce disk access. The map files are opened with a physical block size equal to the data block size delivered by the disk to the bus. This also results in much less context switching between the application program on the file system when using the UNIX operating system. As a result, relatively large amounts of data (8192 bytes) for each table can be kept memory-resident without the application program becoming unduly large. An example of speeds resulting from segmentation into tables and disk buffering is plotting 1000 topologic street line features per second on an HP-370.

Compressing data so that more map information arrives at every disk access is also used to increase efficiency. One primary example is storing of real world map projection coordinates as either sixteen or thirty-two bit integers. Double precision map projection coordinates are stored internally as local offset values from the center of the map partition. Use of thirty-two bit integers in this manner achieves approximately the same precision as double precision values in half the space. Sixteen bit values provide very acceptable precision in one-fourth the space except for engineering, surveying, or COGO applications. Storing coordinates as integers has the additional advantage of integer arithmetic computational processing. All input double precision search coordinates are first converted to internal integer values allowing computations to take place using integer arithmetic.

Another mechanism used to promote efficient access is the use of a sixteen tree spatial index for the frequently searched node table. The nodes in the map are indexed by initially allocating direct references to node records according to their location in a four by four matrix subdivision of the map extent. Each of the sixteen subdivisions matrix elements can directly reference sixteen nodes. When one of the matrix elements needs to index nodes in close proximity that are covered by this individual matrixelement, it is further split into sixteen portions and the original matrix element points to the smaller sixteen matrix instead of directly to the node. This continues on to a maximum of seven levels where the map resolution is reached. This structure readily accommodates a map with sparse and dense data since each cell is only divided on an as-needed basis. It also results in a maximum of eight disk accesses under the worst mis-disk blocking case in an area of extremely dense data. Speeds achieved for node searches are approximately one clock second in a map of 5000 nodes on an HP 370.

These node table search speeds allow for maintenance of topology during data entry and edit. Gaps and overshots at nodes can be eliminated by tying to existing nodes in the current edit map or ancillary map layers. This also eliminates the need for subsequent cleaning operations to remove the 'spaghetti' from the map and does away with nodes 'creeping' to some fuzzy position between a set of nodes.

Permanent and Temporary Views

Users rarely want to operate on the entire database or even on all map partitions in a thematic layer. As a result, a method of selecting from the databases where specified criteria of features is met must be implemented.

The method operates quickly to allow users to rapidly construct different database views and abandon previous views. For flexibility, the selection method includes not only SQL 'Select Where' type conditions but also spatial conditions such as inside of, adjacent to, and in close proximity to. To eliminate re-accessing of data, the separate views can also be combined with the boolean operators AND, OR, NOT and XOR to produce a composite view. Views from selects in the DBMS can be combined with selects in the GIS. Previously constructed views can be input to the select function for further selection.

A simple but inefficient method of storing the views would be to copy the selected spatial data to a new map. This method would obviously increase disk access since the selected data must be written to a disk file and processing would be required to maintain topology. In addition, temporary map views would clutter the user workspace.

Instead of creating temporary maps, the method implements condensed indexing with direct pointers to map features. References to features in multiple databases of multiple map partitions are allowed. The selection criteria is stored with the view to allow for automatic reselection when maps in the view have been updated. A consistent map projection between all the maps potentially in the view is not required since view spatial reference MBR are stored in longitude/latitude pairs and converted to the current session projection 'on the fly' when the session projection is different from that of the map partitions in the view. Integer arithmetic is used on views to promote processing efficiency.

Views are treated for all practical purposes as just another map by the analysis and display processing software. The full path to the map partitions are contained in the view with direct feature references. The result is efficient access to spatial data with very minimal additional disk access or processing to read the condensed indexing information in the view.

For flexibility, one or more views can be saved to a new map. In addition, permanent views can be constructed by saving the temporary views. Permanent views can be retained in the user workspace or placed in a database for global access. Temporary views are saved between sessions to eliminate view re-construction.

Continuous Processing

A required characteristic of a continuous database is that line and area features which cross map partition boundaries appear to the user as not significantly different from features wholly contained in a single partition. To meet this requirement, tools and procedures are used to ensure that during database construction and editing, the primary attribute and boundary coordinates of a line are the same on both sides of a partition boundary. This capability is provided using the methods previously described and additional processing methods that are not disk- or CPU- intensive.

During construction, searches of the database R-tree quickly establishes which map partitions are in the edit window. As data is entered, it is a simple matter to compare the MBR of the incoming data to the MBR of each partition and drop the data into the appropriate partition. The incoming data and the MBR of the partitions are memory-resident and as a result, the scheme requires minimal overhead and operates efficiently.

Lines which cross a partition boundary are divided at the boundary and flagged as ones which cross. During edit, query, or select operations, the composite line can quickly be accessed by using the highly efficient node index. The coordinates of the boundary node identify the adjacent partition by a simple MBR search. The node index of the adjacent partition is then searched and the line attached to the node is returned. This continues across partitions until a line is encountered which does not cross partition boundaries or has a different primary attribute. For area features, since they are formed from edges used in a clockwise direction, the method simply 'turns right' at the adjacent partition boundary node.

The degree of efficiency in these operations results in very little differences in response times between accessing features crossing partition boundaries and ones wholly contained in a single partition. In addition, the map sheets can be formed directly without making a 'mongo map' and tiling into a database.

For data coming from a non-topologic system or a GIS without sufficient edge matching, zippering functions are provided to identify boundary node coordinate mismatches and primary attribute mismatches across partition boundaries. The effect of the functions is to run a zipper around the map borders and determine where the teeth(nodes) do not match. Zippering uses the node index which result in its high efficiency.

Conclusion

Efficient access to a continuous spatial data is provided by the methods described. Limiting disk access through partitioning, indexing, and compression, along with computational prudence results in the rapid response times. The method uses straight-forward algorithms and does not require the user to bear the cost of purchasing a license to use a DBMS to make the GIS operate.

Although current DBMS technology cannot efficiently process spatial data, it is expected that this will not be the case in the near future. Already some DBMS are beginning to show promise. Perhaps some of the indexing algorithms presented here could be implemented in a DBMS for fields of information with spatial characteristics.

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Data Structures for GIS

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Abstract
How data structures are implemented and integrated has critical ramifications on system design, capability, efficiency, expandability, and longevity. Structures which consider the nature of the data they are storing are the key to any successful system, particularly with spatially based information, due to the complex nature of geographical relationships. This paper reviews hierarchical, network, and relational data structures as well as raster and vector data models. It also provides examples and evaluates the integration of these data structures and models into commercial GISs.

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An Efficient Data Structure for Surface Analysis in Vector-based GIS

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Abstract

Surface analyses based on digital topographic data, using a geographic information system (GIS), often involve the processing of large data sets with complicated operational procedures. The design of an efficient data structure improves the effectiveness of a GIS in handling surface information. In general, vector data structures are more efficient than raster structures concerning memory space and processing speed. Three types of vector structures are available for organizing surface information: a point coverage with irregularly spaced data points, a polygon coverage of triangulated irregular networks, and a line coverage of digitized contours. Comparisons among them indicate that digitized contours provide the most efficient data structure. Two relational files are used to construct an efficient structure of digitized contours, a Contour Attribute Table containing topographical and topological information and a Point Location File containing locational data of contours. A surface model for detecting slope lines from digital terrain models is built on this data structure and applied to the topographic database of Idyllwild, California. The data structure enables surface information to be processed with minimally required topographic and topological data elements and thus improves the efficiency of complicated computations in a variety of surface analyses.

Introduction

Three fundamental elements of topographic data are required in surface analyses, the X and Y coordinates of each data point and its elevation conventionally denoted as Z. Most digital topographic data are organized in a raster environment where data points are regularly spaced in X and Y dimensions; e.g, surface elevation is coded at a constant distance of thirty meters in the Digital Elevation Models (DEM) of U.S. Geological Survey (1987). Earlier Geographic Information Systems (GIS) are developed accordingly and organize surface data in raster structures.

Raster data structures are easy to implement and ready for grid-cell processing. Regarding memory space, an obvious advantage of raster structures is that, as data are consistently arranged, only the Z values need to be coded as long as X and Y values are expressed explicitly by a simple function of regularity. However, due to the vast amount of redundant data, empirical topographic databases organized in raster structures tend to require much more memory space than what they save on uncoded X and Y values. Particularly, for large flat surfaces or areas of relatively constant slopes, raster data files usually contain a great deal of data points that are either of identical values or are varying constantly and systematically.

A major criterion for a surface analysis to be efficient is that topological characteristics of areas beyond the boundary of grid cells must be readily available. Simple raster structures are inadequate for surface analyses because, as topological information is incorporated in such structures, the size of the database increases enormously. In some cases, the volume may become so large that even basic procedures of data processing take a great deal of CPU time. Storage-efficient raster structures are available, e.g., the quadtree structure (Mark et el. 1989), yet the saving in memory space is usually obtained at the cost of increased complexity in coding topological information. Consequently, it is very inefficient to conduct any surface analysis which requires frequent processing of topological characteristics based on the modified raster structures.

In general, vector structures are more efficient in terms of data storage primarily because spatial data are organized with variable density. For instance, a large flat surface may be coded by a single data point whereas a constant slope may be accurately represented by a few data points. Surface analyses can be performed much more efficiently in vector-based GIS as a result of minimized data redundancy and improved processing speed. In this paper, major vector structures of topographic data are compared in terms of storage space and processing speed. A data structure designed for efficient surface analyses is presented.

Vector Structures of Topographic Data

In vector-based GIS, topographic data can be organized into either a point coverage, a line coverage of digitized contours, or a polygon coverage of irregularly triangulated networks (TIN) (Peucker and Chrisman 1975, Estes 1986, Dangermond 1988).

A point coverage of topographic data contains the X, Y, (location) and Z (elevation) values of irregularly spaced data points. The coverage may be rearranged through interpolation to generate a lattice coverage of regularly spaced data points. For surface analyses, the data structure and processing procedure of the lattice coverage are similar to those of a raster database thus the lattice coverage is not considered here. Figure 1 shows the coverage of topographic data points of the Palmview Peak 7.5-minute quadrangle in southern California. This coverage is clipped out from the database of Idyllwild 15-minute quadrangle. The original Idyllwild database is created by converting the DEM into a lattice coverage and processed through the selecting procedure of Very Important Points (VIP) to reduce data redundancy (Environmental Systems Research Institute 1987, Chen and Guevara 1987). There are 719 352 data points in the original DEM. The processed point coverage contains 1156 data points.

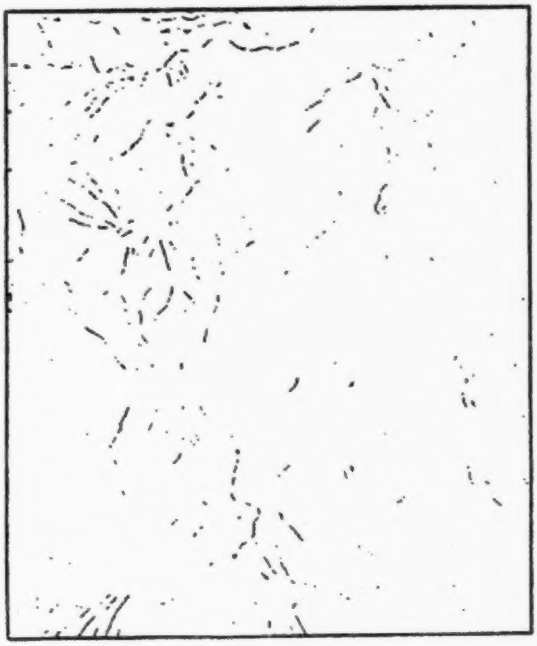

Figure 1: The point coverage of Palmview Peak, northeast Idyllwild, California. Each dot denotes the location of one data point coded with elevation.

Figure 2 shows the line coverage of digitized contours generated from the point coverage. Data files of the contour coverage contain line segments of contours, their elevations, and the X and Y coordinates of the points in the segments. A code of topological information is assigned to each point to differentiate starting and end nodes from intermediate vertices.

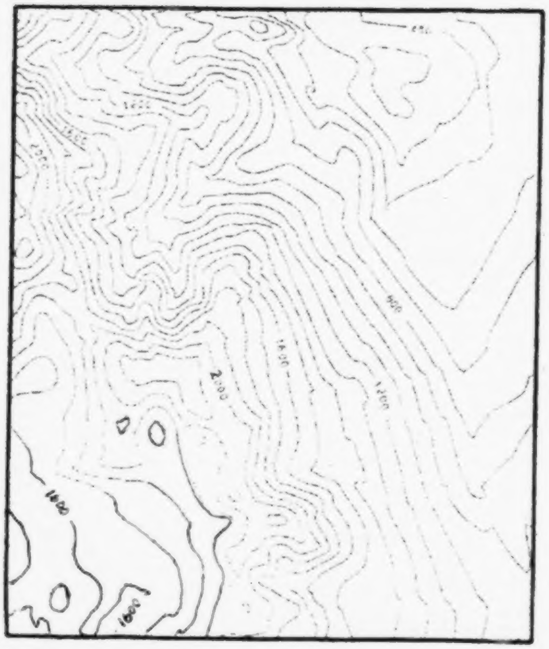

Figure 2: The 100-meter contour coverage of Palmview Peak, generated from the point coverage.

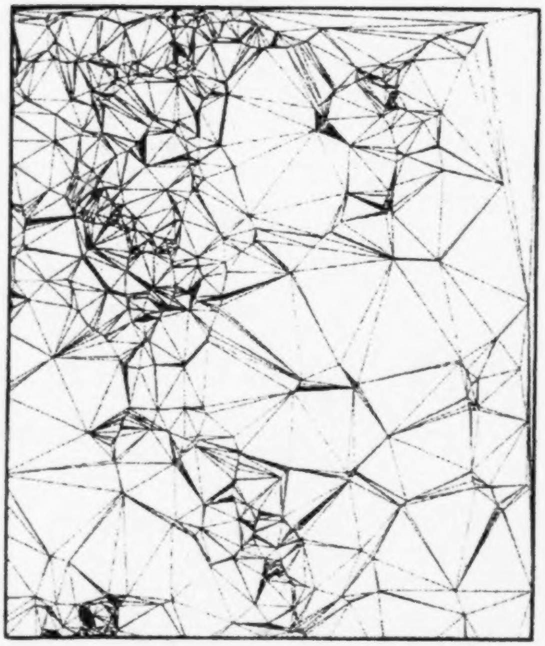

Figure 3: The polygon coverage of triangulated irregular networks of Palmview Peak, generated from the point coverage.

Figure 3 shows the polygon coverage of triangulated irregular networks (TIN) generated from the point coverage. The TIN coverage is a special case of polygon coverages for all polygons are degenerated into triangular facets. Topographic data are coded on the basis of the triangular facets.

Comparisons among Vector Structures

Storage space is the first element to be considered in assessing the efficiency of a data structure for surface analyses. Table 1 shows the volumes of data files organized in vector structures.

Table 1: Data Volumes of Vector Structures

Coverage	Data Volumes (k bytes) Palmview (7.5)	 Idyllwild (15)
Lattice (DEM)	720	2,877
Point	68	128
TIN	606	1,108
Contour (100m)	124	214
CAT-PLF (100m)	83	201

It should be mentioned that comparing the size of the lattice coverage with that of any other coverage is inappropriate because the lattice coverage is converted from the DEM without generalizing while other coverages are based on the data set processed through the VIP procedure. The lattice coverage contains the same number of data points as the unprocessed DEM and is listed only for demonstrating the size of DEM. CAT-PLF represents the proposed data structure derived from the line coverage of 100-meter contours, which will be discussed later.

As far as storage space is concerned, the point coverage is most efficient among vector structures due to the fact that topological information is not incorporated. However, the lack of topological information also makes the point coverage least useful for any surface analysis. This is the simplest data structure suitable only for unprocessed raw data. Furthermore, the map of a point coverage can be hardly interpreted for any purpose. In order to conduct any surface analysis, the point coverage always has to be converted into either a lattice coverage, a contour coverage, or a TIN coverage. Clearly, the advantage of minimal storage space of the point coverage is useful only when the topographic data are to be archived. Since the cost of disk space is relatively low, it is more efficient to organize topographic data in a structure readily available for surface analyses.

Digitized contours and TIN are the commonly accepted means for organizing topographic data (Peucker et al. 1978, Carter 1988). The TIN coverage has certain important features. First, a triangular facet is the smallest indivisible surface with unique and unambiguous surface properties. Second, the number of triangular facets in a coverage is a function of data points. If N denotes the number of data points, then the number of unique triangular facets is between N-2 and 2(N-3)+1. This property enables the analyst to adjust the size of a TIN coverage by choosing an adequate number of data points. Another useful feature of the TIN structure is that surface characteristics of individual triangular facets may be derived mathematically. For instance, the surface area, planimetric area, slope gradient, and slope aspect (orientation) of every triangular facet are available in the TIN coverage. However, these surface characteristics are of little use for surface analyses because their meanings are limited to the area within each triangular facet.

Certain disadvantages of the TIN structure hamper its efficiency in surface analyses. First, the TIN structure is sensitive to edge effects. Since the formation of triangulated networks is bounded by a convex hull, an additional data point near the edge of the coverage may alter the structure of a large portion of the TIN coverage.

Second, the file structure of the TIN coverage is cumbersome. The topographic and topological data may be organized either in a number of relational TIN files or in two attribute tables of a polygon coverage. For instance, in ARC/INFO, a commonly used vector-based GIS, six relational files are constructed for each set of TIN, including the environment file (ENV), the file of the convex hull (HUL), the file of edges (EDG), the file of vertices (NOD), the file of X and Y coordinates (NXY), and the file of elevation data (NZ). Surface analyses often require the processing of surface information beyond the boundary of triangular facets. The cumbersome structure of TIN files creates stumbling blocks for basic neighborhood operations. Answers to queries about the spatial relationship of neighboring triangular facets usually are reached after a number of tedious logical operations. For instance, simple questions such as whether the path along a slope reaches an edge or a vertex or which adjacent triangle should be considered in extending the path may cost a great deal of CPU time in processing through TIN files.

Another disadvantage of the TIN structure is that triangular facets are poor representations of the Earth's surface. It is difficult to identify any spatial pattern from a map of triangulated networks. The output of a TIN coverage must be converted into more understandable forms such as contours or perspective diagrams.

Digitized contours not only provide an efficient structure of topographic data regarding storage requirement (Douglas 1986), they are also ready for graphic presentation and surface analyses. In a vector GIS, a line coverage of digitized contours contains topographic and topological data in an Arc Attribute Table (AAT) which is not designed specifically for surface analyses. A data structure derived from the contour coverage for improving the efficiency of surface analyses is presented below.

The CAT-PLF Data Structure

Topographic data can be organized in two relational files, the Contour Attribute Table (CAT) and the Point Location File (PLF). The PLF is a sequential list of locations of all the points that construct the contours, coded in X and Y coordinates. Table 2 shows a partial list of the PLF of the Idyllwild contour coverage. This table does not include the addresses of data points, which may be added in order to enhance processing efficiency with binary search.

Table 2: A Partial PLF of Idyllwild

X	Y	X	Y
543143	3734040	542876	3734085
524396	3734185	-------	-------
-------	------	524265	3707386
524499	3707473	524044	3706966

The CAT contains the topographic and topological data of contours. Table 3 shows a partial list of the CAT of the Idyllwild coverage. Each record is an arc of a contour labeled by ID. Five fixed-length items are coded: elevation (ELEV), address of the starting node (START), the number of data points (PNT), the number of neighboring contour segments of lower elevation (LC), and the number of neighboring contour segments of higher elevation (HC). Two items of variable length are also coded, the list of neighboring lower contours (LCS) and the list of neighboring higher contours (HCS), in both lists contours are referenced by ID codes. Since the lists of higher and lower neighboring contours are of variable length, they may be saved in separate files for convenience.

Table 3: A Partial CAT of Idyllwild Coverage

ID	ELEV	START	PNT	LC	HC	LCS	HCS
1	200	1	22	0	1	0	8
2	1800	23	47	2	0	6,30	0
3	800	71	49	1	2	17	4,12

START is the relational key between the CAT and the PLF. The locations of vertices in each contour segment are sequentially arranged in the PLF and referenced by the address code of START in CAT. LCS and HCS are the critical elements of the CAT-PLF structure, providing the spatial relationships among segments of neighboring contours. The lists of neighboring contours are important for efficient surface analyses because they minimize the choice set in each local search and thus reduce CPU time in processing topographic data. The extraction of surface information is performed only on necessary records instead of the entire database. The efficiency of surface analyses is further improved by the minimized data redundancy in the CAT-PLF structure. Table 1 shows that this structure is more efficient in data storage than the original contour coverage.

Surface Analyses using the CAT-PLF Structure

Complicated procedures in surface analyses can be performed efficiently using the CAT-PLF structure. Based on this structure, Chou (1989) proposes a method for vector-based GIS to detect the path of steepest descent from any exogenously given location in a surface. The method is developed for detecting the most likely routes of landslide debris along slopes, which is useful for identifying potential sites of deposit and delineating zones demanding slope protection. The problem is complicated because it involves the processing of both topographic and topological data of the coverage. The Idyllwild database is used for testing the method. A 200-meter contour coverage is generalized from the 100-meter contour coverage and then converted into the CAT-PLF files through a FORTRAN program. Chou's method correctly identifies the slope line starting from any arbitrarily given location in an average of 1.6 seconds CPU time on a VAX8820 computer. The efficiency of this procedure relies heavily on the high processing speed contributed by the CAT-PLF data structure.

Other procedures of surface analyses can also be performed efficiently using the CAT-PLF structure. For instance, to generate a perspective diagram (3-dimensional graph) from a contour coverage, one may impose a fishnet grid on the contours coded in the CAT-PLF structure. The topographic profile can be constructed from the intersections between contours and each grid line. Intersections can be identified efficiently because the lists of neighboring contours reduce the processing time in searching for next intersections. Each time an intersection is identified, the next intersection is always on the neighboring contour. Another example is automated generation of intermediate contours. Since intermediate contours exist only between neighboring contours, the lists of neighboring contours minimize the choice sets for data processing thereby saving a great deal of CPU time.

Conclusion

The current GIS technology enables a wide variety of spatial analyses to be conducted efficiently. However, different data structures are suitable for different types of analyses; for example, the same overlay analysis that involves complicated logical and mathematical operations in a vector data structure may be more efficiently performed in basic raster structures. A well designed data structure not only improves the efficiency of a spatial analysis, but also opens the door to more sophisticated analytical procedures.

The major concern in surface analyses is the distribution and the variation of elevation over the X-Y space. As both storage space and processing speed are considered, digitized contours provide the most efficient data structure. The CAT-PLF structure is based on digitized contours and designed specifically for complicated procedures in surface analyses.

Since different data structures are suitable for different spatial analyses while an efficient GIS database can not be constructed in all structures, an important issue for GIS developers is the capability of data conversion among different structures. All the data conversions in this study are automated. The DEM are converted into a contour coverage by ARC/INFO procedures. The Arc Attribute Table (AAT) and the Polygon Attribute Table (PAT) of the contour coverage are then converted into the CAT and PLF files by a conversion program. The next generation GIS must be versatile for different types of spatial analyses such as overlay analyses, statistical analyses, spatial modeling, and surface analyses. Even if standardized data structures are adopted by major GIS in the future, it is still necessary to maintain the data-conversion capability for different spatial analyses to be conducted efficiently.

Acknowledgement

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A Comparison of Partitioned and Seamless Organizations of Spatial Data

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Abstract
For two-dimensional vector-encoded spatial data, consider the partitioning of the area of interest into a set of adjacent tiles. If the spatial data itself is split according to the tile boundaries and the tiles are organized in some manner, then the organization is said to be partitioned. If the spatial data remains unaffected by the introduction of the tiles and the tiles serve primarily as an index to the vector-encoded data, then the organization is said to be seamless. This paper compares the costs associated with partitioned and seamless organizations for performing some common operations on spatial data sets, with particular emphasis on very large thematic data sets. To put comparisons on a concrete foundation, a particular but representative realization of a partitioned and a seamless organization is described.

1. Introduction

For vector-encoded spatial data, the perception of some researchers and vendors of geographic information systems is that seamless models are unquestionably the desired objective [7]. The main contention is that the world is not partitioned into discrete rectangular sections corresponding to mapsheets, and there is no reason why we should not model the world as it really is — continuous [1]. From a practical point of view, the argument is that partitioning by mapsheets introduces storage overhead and makes certain operations such as tracing and connectivity analysis tedious if not impossible [13].

We acknowledge that the seamless database is clean and simple, and that for certain spatial operations it may be preferred. However, in the following, we attempt to convince the reader that the controversy over the seamless versus the partitioned approaches is very much alive. Indeed, arguments are given which would indicate that for large thematic databases there are very good reasons for partitioning by mapsheets, and that this is possible without significantly affecting either storage requirements or costs of operations.

The strength of the partitioned spatial database comes from its ability to adopt the divide-and-conquer approach to retrieval and processing [18,19,21,23] The partitioning of the study area into mapsheets (tiles) is the division aspect. This aspect introduces artificial information into the database, namely, the information along the boundaries of the tiles (the seams of the partitioned database). The conquer aspect is achieved by storing sufficient information in each tile so that spatial operations can be performed on a tilewise (tile by tile) basis. Each tile is independently retrieved and processed. In addition, within each tile sufficient topological information can be retained about neighbouring tiles to permit the effective execution of topological operations such as tracing and connectivity analysis. The complexity introduced into the database by the additional information at the seams is the price that is paid for any improved performance obtained from the conquer aspect. In the following, we argue that for large thematic data sets this price need not be high.

2. A Topological Vector Organization

The underlying assumption in the following discussion is that the spatial data is encoded in a vector format. The merits of such a format as opposed to a raster one are an ongoing controversy and are discussed elsewhere [2,16]. The scope of spatial data considered in this paper is restricted to data describing collections of regions (objects) in two-dimensional space. We are primarily interested in Geographic Information Systems (GIS) dealing with collections that totally partition an area of interest into a set of mutually-exclusive regions. Typical of these applications is the handling of thematic maps that describe phenomena areally distributed on the surface of the Earth. Examples of such thematic data applications are land use classifications, forest covers, and soil types. Of primary interest are very large thematic data sets which consequently must reside on secondary storage.

There are a number of choices for the format of vector encoded spatial data [2,16,22]. However, in order that certain operations such as tracing be performed in an effective manner, it is paramount [13] that the format include topological information, that is, spatial and attribute information about neighbourhoods. We briefly describe one such set of formats; this set is typical of the formats adopted by well-known topological GIS's such as POLYVRT[15], GEOVISION[13] and especially TIGER[12]. These formats are used as the underlying vector data structure for describing in the next section the seamless and partitioned data models.

A polygon network corresponding to a theme (or coverage) can be represented using three entity types: polygons, chains and nodes. A chain is a sequence of edges defining a boundary of a polygon (usually separating two polygons). It is typically represented by an ordered sequence of points corresponding to the beginning and end points of the edges that make up the chain. The nodes in a network are the first and last points of all chains in the network. The nodes are the meeting points of three or more polygons (i.e., the meeting points of three or more chains).

The central elements of a topological vector data model are the chains, which are usually stored randomly in a *chain file*. Each record in the chain file gives the start/end nodes and the left/right polygons of a particular chain. In addition, each chain record points to two other chains having a node in common with the start and end nodes. This technique gives the ability to determine all the chains intersecting a particular node and enables the threading[12] of chains around a given polygon. The coordinates of the points composing a chain are not explicitly stored with the chain record; instead a pointer is made to a location in a separate file, the *point file*, which lists these coordinates. Such a strategy allows certain operations, such as connectivity analysis, to be performed without requiring the costly retrieval of the coordinates of chains.

To provide access to the polygons in the network, a *polygon file* can be used. Each record in this file corresponds to a distinct polygon in the network. Each record stores a pointer to a chain in the chain file which has the associated polygon on its left or right side. To accommodate polygons with holes, further organization of the polygons in the polygon file is necessary. Weiler[24], for example, uses two additional pointers in each record of the polygon file. One pointer provides a link to a polygon which coexists (neither lies within the area of the other), while the other refers to a polygon which is entirely contained within (a hole).

The structure so far described does not yet provide easy access to the spatial extent of any particular attribute of a theme (e.g., in a forestry coverage, the polygons whose attribute might be 'spruce'). This can be enhanced by placing appropriate attribute information in the records of the polygon file. The polygons having the same attribute can then be linked by means of pointers, and a separate file can be set up, which, for a particular attribute, points to the first polygon with that attribute.

Alternatively, the separate file can, for each attribute, list all the polygons in the polygon file which possess this attribute.

Many spatial operations can be performed effectively using the organization outlined above. This is true in particular for operations which in [21] are classified as *attribute-based* (given an attribute, what are its locations?). Thus, for example, given a polygon or an attribute of a coverage (which is equivalent to a list of polygons), it is necessary only to thread through the chain file to determine the chains composing the boundaries of that polygon or attribute. The boundaries are then obtained by retrieving from the point file only those coordinates describing the relevant chains; no extraneous information is retrieved. Also, because of the topological content within the chain file, the *topological operations* of tracing and connectivity analysis can be performed in an efficient manner.

Location-based operations [21] (given a location, what are its attributes?) are more costly. Included in this class of operations are point inclusion and windowing. To improve the situation, the TIGER system, for example, includes another file which we here call the *node file*. Each record in the node file corresponds to one node in the polygon network. The record gives the coordinates of the node and a pointer to one chain that emanates from that node. To assist in location-based operations, a spatial ordering by Peano keys [5] can be imposed on the records of the node file. Binary search methods can then be used to help identify nodes relevant to a location-based operation. For the point inclusion operation, using the Peano key of a given point allows rapid determination of a network node nearest to the point (i.e., nearest in Peano order). The set of chains emanating from the nearest node are obtained from the threaded chains in the chain file. This set of chains divides the space around the nearest node into neighbourhoods, one of which may be the polygon containing the point. If none of the neighbourhoods contain the point, then this method has at least identified a reasonable location within the polygon network from which the search for the enclosing polygon may begin. For the windowing operation, this node file organization provides similar improvements in performance. By extracting from the node file the set of nodes contained within the window (note that this set may be empty), the search for candidate polygons intersecting the window is localized to the neighbourhoods of the nodes within this set.

However, even with these refinements the spatial data model described above, which is entirely vectorial, is completely inadequate for the thematic overlay operation. This operation is both attribute-based and location-based and is called a *hybrid operation* in [21]. Thematic overlays involve the complete traversal of the polygon networks representing two or more themes. Restricted by the lack of information on the location of polygons, for large thematic data sets, the overlay problem typically involves multiple retrievals of polygons and their boundaries.

The quest to improve the performance of the polygon overlay and the location-based operations has been the primary motivation for introducing additional structures on top of the underlying vector one. One such structure is the subject of the next section and the theme of this paper; another which is worthy of note is the *R-tree* [8]. The R-tree requires that the polygons in a polygon network be tightly enclosed by rectangles; these provide estimates for the locations of the polygons in space. The coordinates of the rectangles are concatenated to the records of the polygon file. The polygon file can now be spatially ordered and hierarchically organized by the bounding rectangles (the R-tree), providing improved access to those polygons that intersect a specified location.

3. The Seamless and Partitioned Data Organizations

For vector-encoded spatial databases, a method of improving the efficiency of the polygon overlay and location-based operations is to introduce a tessellation of the underlying space into a exhaustive collection of mutually exclusive cells. Each cell either *references* those polygons that are contained within it or intersect it (the seamless approach), or each cell *contains* that portion of the polygon network that intersects it (the partitioned approach).

In practice, it is usually desirable to select cells to be rectangular (the cells are then also called tiles, mapsheets or frames) and to allow the cell sizes to vary according to some hierarchical subdivision principle. For rectangular cells, the subdivision principle allows the tiles to be organized into a quadtree. Many benefits accrue from a quadtree organization, the most significant being the ability to use direct addressing techniques to access cells (or, the buckets associated with them)[10,14,20. There are various strategies for selecting tile sizes depending on such criterion as the local density of data [6,21]. In the following, no assumptions on the tile sizes are made, only that they are identical for both the seamless and the partitioned approaches. This allows comparative arguments in the next section to be made more easily.

The splitting of a polygon network by a tessellation grid can be achieved in a number of ways. Each time a tile boundary intersects a chain, the chain is split into two new shorter chains. Each such occurrence introduces one additional chain to the chain file, one additional node to the node file, and two additional points to the point file (one end point each for the two new chains which meet at the new node). For a polygon network, this splitting process can significantly increase the size of the chain and node files and mildly increase the size of the point file. However, for typical thematic data sets it is not unreasonable to assume that the storage requirements for the point file overwhelmingly dominate that of the chain and node files. It can therefore be argued that the partitioning process has only a moderate effect on the storage required by these three files.

The partitioning of a network also splits polygons into a number of smaller ones (see Figure 1). If processing is to be possible on a tilewise basis, it is necessary to organize these polygon portions within each tile. For the network configured in Figure 1, a Weiler-type organization of the polygon portions is illustrated in Figure 2. In Figure 2, a

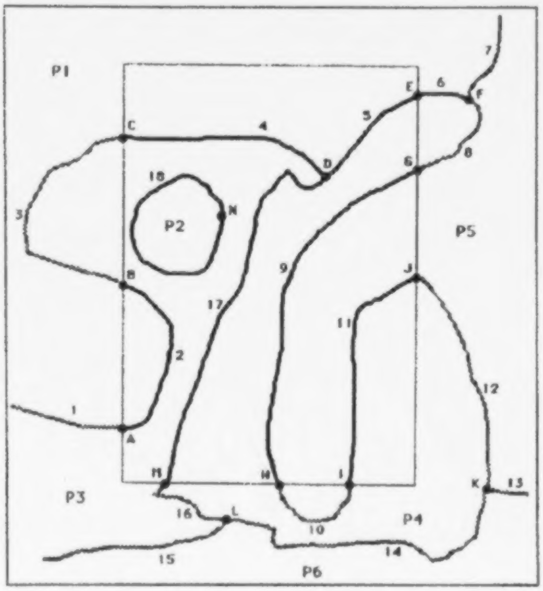

Figure 1
Tile Intersecting A Polygon Network

polygon portion is identified by its name and by a pointer to a chain along its boundary. The right arrow points to another polygon which coexists whereas the down arrow points to a hole. The Weiler representation can be implemented as a binary tree, using a file which we here call the *polygon/cell file*. The number of records in the polygon/cell file is equal to the total number of polygon portions and is much larger than the number of records in the polygon file. However, for the same reasons given above, for typical thematic polygon networks, the size of the polygon/cell file will usually be insignificant in comparison with the point file. A file structure similar to the polygon/cell file is also necessary using the seamless model. In the seamless model, only a list of polygons (with pointers to chains) intersecting each tile needs to be maintained in the polygon/cell file. Note that in both the seamless and partitioned models the polygon/cell file is distinct from the polygon file.

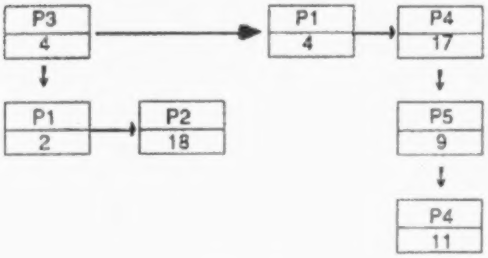

Figure 2
Weiler Organization

Note that chains introduced by the tile boundaries, which are necessary for defining the extents of polygon portions, are excluded from the chain file. Boundary chains (seams) can easily be computed whenever they are required (assuming, not too unrealistically, that the coordinates of the tile boundaries are available). For example, in Figure 1, it is easily determined that the polygon portion of P4 which has chain 11 as part of boundary can be completely defined by joining one of its endpoints to the bottom right corner of the tile and then joining this to the other endpoint of chain 11. In Table 1, chains with asterisks are those in neighbouring mapsheets which are connected to chains in the present tile.

Also note that the location of a node introduced at a tile boundary is required only for operations which also process the coordinates of one or more chains meeting at that node. In this case, the coordinates of such a node are already available from the chain being processed. Thus, after all, there really is no need to store in the node file the nodes introduced at tile boundaries; that is, partitioning need not affect the node file (if a node file is used).

Partitioning, however, does have an effect on the polygon file. Each record in the file, which corresponds to a polygon, now points to a tile which intersects the boundary of the polygon, rather than to a chain composing its boundary.

The crucial observation can now be made. In the partitioned approach, it is possible to arrange that each record in any of the polygon/cell, chain, node and point files is associated with precisely one tile. The tiles are quite independent (the one exception is that chains in one tile contain pointers to connecting chains in neighbouring tiles). This provides the ability to do tilewise ordering of the records (by Peano keys, say) of all four files. A preferred organization is to assign a bucket to each tile and use direct addressing techniques to retrieve in one input/output operation (I/O) all the records for that tile; this arrangement is assumed in the next section. However, in some environments, it may be better to use a separate bucket organization for each file.

4. Comparison of Costs of Operations

The tessellation component (i.e., the polygon/cell file) of the seamless approach is clean and simple. It serves simply as an index to attribute (e.g., polygon) information intersecting each of the tiles in the tessellation. The underlying polygon network remains intact. On the other hand, in the partitioned approach, some complexities in the data structure are introduced by the splitting of the polygon network at the tile boundaries. In addition, there is a significant increase in the storage required by some of the files in the partitioned approach, although it is argued in Section 3 that, overall, this increase for typical thematic data sets is modest. The question remains: using the partitioned model, is there adequate compensation for this increase in complexity and storage requirements?

To this end, the two approaches are compared in terms of the costs of some common operations performed on thematic data. The measure of cost is the number of I/Os required to complete an operation (the processing costs associated with each of the given operations are assumed to be less important).

For an attribute-based operation, consider the retrieval of the boundary points of a specific polygon. Using the seamless approach, the polygon file is first accessed to obtain one chain lying on the boundary of the polygon. Assume that this can be accomplished in one I/O (using, for example, direct addressing techniques). The remaining chains along the boundary of the polygon are obtained by traversing the appropriate chains in the chain file. Since the chain file cannot be spatially ordered in a meaningful way, a separate I/O is required for each chain so retrieved, in the worst case. (Some improvement may be possible here if, say, the chains are spatially ordered by the coordinates of one of their endpoints.) In addition, a separate I/O is required to obtain from the point file the coordinates of the points composing each chain. Thus, the retrieval of the boundary points of a polygon with c chains using the seamless model normally requires 2c+1 I/Os in the worst case. On the other hand, using the partitioned approach, again one I/O is required to access first the polygon file to determine one tile which intersects the polygon. By traversing the chains within this tile, other tiles intersecting the given polygon are obtained and traversed. Therefore, if the polygon intersects t tiles, its boundary points using the partitioned approach can always be obtained in t+1 I/Os. Thus, the costs of two approaches for polygon retrieval are not comparable; 2c+1 may be larger or smaller than t+1. Summarizing, in the seamless model, the cost of the operation depends on the number of chains involved in the operation, whereas in the partitioned model the cost depends on the number of tiles involved. This is a general observation applicable to all operations performed on the polygon network.

Chain	Start Node	Start Pointer	End Node	End Pointer	Left Attribute	Right Attribute	Coordinates Pointer
2	A	1*	B	3*	P1	P3	→
4	C	3*	D	17	P1	P3	→
5	D	4	E	6*	P1	P4	→
9	H	10*	G	8*	P4	P5	→
11	J	12*	I	10*	P4	P5	→
17	D	5	M	16*	P4	P3	→
18	N	18	N	18	P2	P3	→

Table 1
Chain File

Thus, a similar observation holds for a topological operation such as tracing. If the thread that is traced is composed of c chains and intersects t mapsheets, then the cost using the seamless model is 2c I/Os in the worst case as opposed to t I/Os using the partitioned one.

Significant advantages of the partitioned approach are realized for location-based operations such as point inclusion. The tile containing the given point is first determined (computed). The data for this tile is retrieved and processed; only one I/O is required. On the other hand, using the seamless approach, the set of candidate polygons which intersects the given tile are first obtained by accessing the polygon/cell file. The candidate polygons are then sequentially processed, each requiring the separate retrieval of all the chains and points composing its boundaries. In the worst case, all of the candidate chains must be retrieved. Similar advantages of the partitioned approach are realized for the windowing operation. The tiles intersecting the window are determined (often simply by computation), retrieved and individually processed. For every tile retrieved, some information is always relevant to the window. Using the seamless approach, all the polygons (their chains and points) which intersect the window must be retrieved and processed. However, in this case, not every polygon (chain) retrieved is relevant to the window.

The greatest advantage of the partitioned approach is realized for the thematic overlay operation. The corresponding tiles of two or more coverages are individually retrieved and overlaid (the power of the divide-and-conquer capability is fully realized here). If the sizes of the tiles from separate themes do not correspond, the larger tile may require splitting (this assumes the same decomposition principle is used for both themes). Using the seamless approach, an overlay is performed of all polygons which intersect a particular tile. This requires numerous I/Os in comparison to the two I/Os (assuming two themes) required by the partitioned approach. Since some of the polygons in this tile have influence in neighbouring tiles not yet processed, it is desirable to retain these in memory. For very large thematic overlays, however, this can lead to memory overflows. Consequently, multiple retrievals of polygons may be required, adding further to the cost of an operation that is already very expensive.

5. Conclusions[1]

A frequent objection to the partitioned spatial data model is that it may require user interaction with tiles. Although this is a *feature* provided by some commercial systems, it is possible and probably desirable to have the seams introduced at the tile boundaries appear transparent to the user. The main purpose for the partitioning is to provide a physical organization of the data, which gives a performance level that is basically independent of data volume[2]. That is, the partitions are meant to supply a physical view of the data, and should not interfere with the logical view. The various components of the polygon network (e.g., the node file) can still be placed in the context of a relational database [3,11,17].

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[1] The arguments and conclusions of this paper are made in the absence of the Proceedings of the *Symposium on the Design and Implementation of Large Spatial Data Bases*, NCGIA, Santa Barbara, California, July 1989.

Another objection to the partitioned approach is that it is undesirable to split objects (polygons) at tile boundaries. However, there is no difficulty in reconstructing a polygon. Just as for an unpartitioned vector model, it is necessary simply to traverse the boundary chains of the polygon. Whether or not this increases or decreases costs depends on the make-up of the polygon and of the tessellation (see Section 4).

Still another objection to the partitioned approach refers to the additional costs incurred during the splitting and merging of tiles. However, these costs are not prohibitive. The splitting of a tile can be viewed simply as an overlay operation, which should not be too costly since processing is localized to the tile being split. The merging of tiles can be accomplished by traversing the polygons within the tiles, joining the required polygon portions and chain segments during the process. Note that for processing purposes it is not necessary to merge the chains segments at all; indeed, there are some advantages to leaving the chains in their segmented form.

There are other potential advantages arising from the partitioned model, in addition to the improved performance obtained for the overlay and location-based operations:

(1) The partitioned model is particularly suitable for parallel I/O and processing [4,9,25].
(2) The partitioned approach enables the effective transmission of data; independent pieces are easier to transmit than large interdependent ones. This capability is critical in a network environment.

In summary, although the arguments given are far from conclusive (indeed, they depend on a particular but representative choice of the vector, seamless and partitioned models and on the sizes and organization of the tiles), we believe that there are strong reasons for continued research into large partitioned spatial databases. This is especially true in view of the recent advances in parallel computing technology for which the partitioned approach appears to be particularly suited.

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2 To achieve performance levels independent of data volume is also the main reason for introducing tiles in the seamless model. We contend that the comparative success of the seamless and the partitioned models in achieving this objective is not a closed issue, but rather an open question.

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Data Issues and Remote Sensing

Session F6
Data Issues

Using CAD Data in a GIS

Automated GIS Data Conversion Technology with Case Studies

GIS for Forest Information Management: A Case Study

GIS'90 Symposium

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Using CAD Data in a GIS

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Abstract
The most costly component of implementing a GIS capability within an organization is data conversion. Consequently, the ability to use existing digital data that may already exist in CAD systems or in other GIS's is extremely important. Unfortunately, there can be numerous (and very frustrating) problems encountered that make digital data conversion a nightmare. To avoid these conversion problems, the GIS users can follow a series of logical steps and rules for evaluating and converting existing digital map data. These steps include defining a data definitions matrix, defining data organization rules, and defining symbolization rules before any data are either digitized or converted. They also included rules of conversion that relate to coordinate systems, transforming non-topology based vector data into topological data structures, and attaching attributes to the geographic features in the GIS database. If a set of rules and procedures are followed, then the conversion of existing digital map data can realize major cost savings and get the new GIS user into production in a much shorter time frame.

The Problem

Upon procuring a GIS, many organizations are faced with the dilemma of how to populate the database. As an example, consider a City as the new GIS user. Typically, they have map source documents scattered throughout the organization. Each department may have their own map set. These documents are at different scales, in different condition, and so on. Further, many of these documents will have no geographic control on them. To make matters more interesting, one group has digitized their particular map set with a PC-based CAD system and would like to put these data into the GIS. At the same time, the users are struggling with the decision as to whether digitizing should occur in-house or under contract with some conversion house. Then, just as the GIS users group begins to develop a solid plan for developing their digital map database, someone discovers that a sister organization has digitized the basemap for the City. However, these data currently reside in a CAD environment.

Obviously, solving the problem of data entry can appear to be a somewhat daunting effort. As much or more effort needs to go into the definition and prototype development of the digital map database as does the actual procurement of the GIS hardware and software. As can be seen from the above example, there are a variety of issues that add complexity to the process. One of these is how to integrate existing and future digital map data that was complied using CAD system. In the example, there are three possible sources of CAD data. The first is the existing in-house PC CAD data. The second possible source will occur if the City decides to have contract digitizing and the award is to a conversion house that has only CAD systems. The third sources is the sister organization with the Intergraph system.

Typically, there is considerable pressure to use CAD data because it will "get us operational more quickly so that we can show management that the system can product useful products". The watch phrase is, "Look before you leap"! Using CAD data in a GIS can be a disaster without proper evaluation and processing. If done correctly, CAD systems can be a extremely important data source for a GIS. This evaluation requires that the users understand what the map data use requirements are. It also requires that the evaluators understand a number of philosophical and technical differences between CAD and GIS.

The key difference between GIS and CAD is that a GIS is designed to build a consistent information management environment based on geographic data while a CAD system is designed for developing a database of drawings that can be used for inventory, design, and other related activities. A map can be treated as a drawing but a drawing can never to truly treated as a map. If a CAD system is to be used to digitize map data, then the map must be treated as a map and not a drawing. The following is a short discussion of several key concepts that must be followed when using a CAD to collect geographic data.

Understanding CAD Data

Before beginning a discussion of how CAD data should be processed for integration into a GIS database, it is important to understand several key concepts regarding how data should be stored within a GIS. These concepts are not necessary components for building a CAD database. However, if they are not used in building the CAD database, the CAD data becomes much more difficult, if not impossible, to use in a GIS database.

Projections/Coordinate Systems

A GIS requires that data be stored using some projected coordinated system. A very common system for municipalities in the United States is the State Plane Coordinate System. There are many reasons for storing the coordinate data in a consistent and definable manner. These reasons include area computations, length computations, edge match between map sheets, the need to build seamless/continuous layers, and map plotting to scale with a reference grid. There may also be legal considerations.

In a CAD environment, data can be collected in any arbitrary rectilinear coordinate system that preserves relationships within a drawing. Thus, a map could be digitized in inches and stored in the CAD drawing database in inches. Whenever that map is plotted in the CAD system, it will look correct. However, if those same data are exported into a GIS, they will, when plotted, bear absolutely no relationship to map data stored in the GIS. The best case scenario for data not in a projected system is that it will have to be 'rubber sheeted' to fit the GIS database. There are several problems with this. First, it is one more processing step. Second, it will introduce error into the data that was not originally there. Third, it will require an additional QC step. Further, if the CAD system has COGO tools and these were used to enter survey data, then the GIS must have tools that allows for 'fixing' monumented points. This is important because rubber sheeting is a global transformation which will shift all coordinates.

Edge Match

A good GIS is designed to allow the users to develop a seamless map environment. This means that the software and the database structure support the ability to edgematch data within a layer across map source document boundaries. If a CAD system has been used to collect map data on a sheet by sheet basis, in all probability there has been no edge match performed. Therefore, to use these data, an edge match process will have to be performed and the results validated. Sometimes, in the CAD environment, many sheets will have been digitized into one drawing file. In this case, edge match has been performed. However, there is now the alternative problem. Most GIS partition the map data for better processing efficiency. Therefore, data in which all maps are in one file will have to be partitioned into smaller units. There is still an additional processing step.

Topology

In a GIS, a data storage philosophy called topology is used. In this environment, each intersection or node contains information about what lines are associated with it. Further, each line contains information about what nodes are at the endpoints. Thus, a topological data structure explicitly stores connectivity information. CAD systems have no such counterpart. Therefore, no matter how data are collected in a CAD system, the data are going to have to be processed in the GIS using a 'spaghetti' to topology transformation. This process takes a set of raw lines and creates a topological structure and all related connectivity information. If maps are to be digitized using a CAD system, problems encountered in running the spaghetti to topology process can be minimized in several ways. First, 'snapping' must be used to digitize the data. Second, if data share lines, snapping between layers should be used to avoid slivers. Third, all data for one theme, such as parcels, should be digitized into one layer. Lines from another layer, such as rights of way, should be stored in the ROW layer and not the parcel layer and visa/versa.

Text Nodes/Attributes

One of the reasons for using a GIS is the ability to use spatial data and attribute data in a common and seamless environment. If the CAD system is going to be used to collect data for a GIS, it is extremely useful to digitize 'tag' locations. These tag locations are used to automatically label point, line, or area features with an attribute. This attribute can then be used as a key into an attributes database. Point features should be digitized as symbols and should have a symbol name that is equivalent to that point features key attribute. For line and area features, the easiest method is to digitize a text node either on the line or in the polygon. The GIS can use these text nodes to perform an auto-tag operation. If text nodes are not available, then the GIS user is faced with re-entering a tag or label for every imported point, line, and/or area feature. This can be very time consuming or even impossible if the original source documents are not available.

Symbology

In a CAD environment, symbology can be used almost entirely to replace basic attribute coding. Colors, line styles, and fill styles allow the CAD user to visually differentiate data layers and by inference to know what a feature is. For example, a manhole may always be represented by a circle with a plus in it. While these same tools are available in a GIS, the GIS typically handles symbology differently. Further, a GIS uses attributes for context and symbology as a way to show context: symbology is an adjunct rather than the end product. In a GIS, for example, it is quite feasible to have a manhole displayed using different symbols even though it has only one key attribute. This problem is exacerbated by the fact that many CAD/GIS translators have no way of handling symbology information effectively. Therefore, if using a CAD to build a GIS map base, do not rely on symbology any more than necessary. Use the tools in the GIS to symbolize based on attribute.

Layers vs Themes

Typically, in a GIS, data are collected in logical groups called themes. An example of a theme is all those entities associated with the gas utility. In a CAD system, the gas utility would typically be stored in many different layers where each layer is associated with a class of data, such as two inch pipes. The gas theme could be stored in dozens of layers. Since the GIS is using topology to store the data and because the GIS is also used as an analytical tool, the need to store all these layers in one gas theme is very important. If CAD data are being used and the data are stored in many layers, the GIS user is faced with having to merge these layers together, check their consistency, and validate the overall topology. This can be a very time consuming task. Therefore, if using a CAD as a data source, conversion to a GIS environment is enhanced if the data for a theme are more integrated in fewer layers.

Geometric Types

CAD systems usually 'understand' many different geometric constructs such as lines, circles, arcs, parabolas, spirals, conics, and so forth. Most geographic systems understand only a limited subset of these geometric constructs. Therefore, when compiling data in a CAD for use in a GIS, use the minimal subset of points, line complexes, circles, and circular arcs. In this way, all the data will be imported into the GIS.

The above are the most problematic when transferring data from a CAD system into a GIS. If the data meets the organizations requirements in terms of content and the following simple checklist is followed, importing the CAD data is feasible.

1. Snapping was used when building the CAD database.

2. The data are in a projected coordinated system, such as State Plane.

3. Layers are grouped as much as possible.

4. A text graphics layer is available to use as an auto-tag file.

5. Edge match has been performed.

6. Symbology is not required to differentiate data.

7. A layer of data, such as parcels, does not require other layers to complete the line work.

8. Simple geometric constructs have been used.

If you decide to use the CAD data, then a set of steps must be followed as part of the transfer process.

Processing CAD Data

Figure 1 depicts the steps that are usually followed when processing CAD data for storage in a GIS database. Additional steps may be necessary, especially if editing is required.

Get CAD Data

The first step is to get an ASCII representation of the CAD data on the proper media. There are many ASCII interchange formats. Usually several are available with a given vendor's CAD system. The most commonly used interchange formats are DXF, IGES, and ISIF. Another interchange format available from some vendors is DLG 3. If DLG is available, use it, since it is designed for the interchange of cartographic data. Before choosing which format to use, make sure that your GIS supports that format! Once a format has been chosen, decide on the media. Typically, media will be a floppy or tape. In either case, make sure that your organization has some mechanism for reading ASCII data from the media on which the CAD data are being supplied. One other point of consideration is that these interchange files can be considerably larger in size than the original CAD drawing file. A one megabyte drawing could require ten megabytes in the interchange format.

Load CAD Data Onto System
Once the media with the data has been received, the data have to be loaded onto disk in the GIS environment. This may sound like a trivial task. However, if the media were generated on a system using an operating system that is different from that of your GIS, considerable effort may be required to determine how to read the media. This is especially true of tape cartridges and nine track tapes. The media may have to be generated in different formats before success is achieved. Once the sequence for reading from the media is known, document it.

Process CAD Data
The next step is to read the CAD data using the GIS reformatter. This step will typically generate a file in the GIS that is in the GIS format but contains no topology. If there are geometric constructs in the CAD data that are not supported by the GIS reformatter, these should be reported at this time. If they do exist in the data, then some method for obtaining these data, which will be missing from the GIS file, will have to be developed.

Perform Spaghetti to Topology
In this step, a tool in the GIS is used to process the CAD data and generate topology. This step will typically:

Remove duplicate lines,
Generate nodes at line intersections,
Remove spikes,
Close gaps, and
Remove slivers.

The end result is a data set that has topology. However, it may not be valid topology. A validation step may also have to be run (see below). A very important point is that the spaghetti to topology process is going to modify the original CAD data. Therefore, after the process is complete, a check plot should be made and compared against the original data.

Remove Redundant Nodes
Many CAD systems have limits on the number of coordinate pairs in a line. They also have line complexes. The end result is that the CAD data in the GIS will probably have many extraneous nodes that are not necessary in the GIS. Therefore, a simple step needs to be run that removes these nodes as it generates data that is closer to reality.

Run Polygon Formation
If the CAD data are of polygonal features, such as parcels, a polygon formation process must be run. This process usually also validates the topology. If there are any errors in the data, they will be identified during this step. Errors will have to be interactively corrected before polygon formation will run to successful completion. It is usually at this step that users may suddenly discover that the great looking CAD data is in fact useless. If too many edits are required, you must question the validity of using that CAD data in your GIS database. The end result of this process is a polygon data set that is topologically clean, islands have been resolved, and areas computed.

Fit Data
Once the CAD data have been cleaned and validated, they can be fit into the GIS database. If the CAD data have been collected in the same coordinate system as the existing GIS data, then this step should be very straight forward. If the data are in a different system or do not fit, then additional processing will be required. This usually involves some form of rubber sheeting. In order to use rubber sheeting, common control points must be found in both the GIS coordinate system and the CAD coordinate system. A minimum of four control point should be used. However, the more points that are available, the better the fit will be. This may sound like a simple step but can quickly turn into a very frustrating experience if adequate control cannot be found. For example, no State Plane coordinates can be found for any of the points on the CAD files. In this case, check with other departments or organizations for control. A good source of control is the highway department, since many streets and highways have been surveyed.

Perform/Check Edge Match
Once the data have been fitted into the GIS database, the next step is to perform and/or check edge match. This step is to insure that dangling lines in the newly added data tie to lines in the existing database. If the new lines do not tie, then some process must be followed to snap these danglers. The reason for this step is that we are trying to build a seamless and continuous spatial database. It is very hard to run a shortest path analysis if the streets do not tie correctly!

Re-tag and Symbolize
The final step in the process is to add context to the spatial data. This involves adding a key attribute to each geographic feature and symbolizing the data for graphics presentation. If the CAD data has a text layer for the newly added data, most GIS have a method of using the text node locations to perform an auto tag/label procedure. This insures that the user does not have to manually re-tag features. Even so, a validation step should be run to insure that all features have been tagged. If there is no text layer, then a manual tag effort will be necessary.

The final step is symbolization. Use whatever tools are available in the GIS to allow symbolized graphics presentation. Most systems allow global symbolization based on the attribute characteristics of the data.

Conclusion

If all the conversion steps are successfully performed, you will have a GIS database built from a CAD source. Obviously, there is some effort involved in the conversion process. The question that must be asked is whether less effort is required to re-digitize the data. If the answer is yes, then do not even bother trying to use the CAD data. This suggests that before a final decision is made, a small prototype conversion should be run to validate that the data can be successfully converted and that the effort required to convert is less than the effort to re-digitize.

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Automated GIS Data Conversion Technology with Case Studies

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Abstract
For the last five years the Automated Mapping and GIS market (AM/GIS) has anxiously awaited the arrival of automated data capture or "scanning" technology to speed the conversion of existing hardcopy maps and facilities drawings into intelligent data. This paper presents several case studies in which automated data capture technology is being successfully employed in the conversion of hardcopy documents into intelligent digital data for use on AM/FM and GIS systems. For each of these cases a comparison is presented showing the quality improvements, time savings and cost savings resulting from the use of this technology.

Introduction

Modern scanning technology was introduced in the early 1980s. At first, it was hailed as a miracle solution that would magically turn data conversion into a totally automated process. Automatic raster to vector conversion and automatic character and symbol recognition promised to eliminate the expensive, labor-intensive aspects of conversion projects.

Unfortunately, these initial claims seemed inflated and 'scanning' technology began to conjure up images of hours at an edit station correcting 'automatically vectorized' drawings. Then unintelligent raster and incremental conversion systems were developed, but it was found they did not offer the analysis capabilities typically required by a Geographic Information System (GIS). Costs decreased, but at the same time, so did the intelligence, quality and value of the resulting systems.

These disappointments were caused by two understandable errors. First, scanning technology was incorrectly oversold as a cure-all. Second, and more importantly, scanning both provides and requires a whole new approach to conversion. Scanning is only one ingredient; many technologies must be effectively integrated to allow the entire operation to be successful. For example:

- Optical disk technology is necessary for storage and access to large amounts of grey scale image data.
- High speed dedicated processors are needed to provide efficient raster-to-vector conversions.
- Artificial intelligence techniques must be integrated to provide sophisticated line and symbol classification.
- High resolution interactive raster and vector graphic workstations must be employed for efficient interactive scrubbing, map registration, vector editing and attribute assignment.
- Local area networks (LANs) must connect numerous workstations to allow images and data to be easily accessed and transported between processors.
- All of these technologies must then be carefully integrated into a finely tuned, automated production management system.

In other words, for scanning to replace manual digitizing as a more effective means of GIS conversion has required the development of an integrated Automated Data Conversion (ADC) process. By combining these technologies, it has been possible to significantly increase the quality of GIS conversions and, at the same time, reduce the amount of time required to complete a project, particularly a large, complex project.

Definitions

Because integrated ADC technology is so new, much of the terminology associated with it is not yet fully defined or consistently used. Therefore, before describing the various technologies and how they are integrated, it is important to first define some of the basic terms as they are used in this report.

GIS Conversion:
The compilation and digitization of a related and consistent set of data to produce the intelligent graphic and non-graphic information required to support a Geographic Information System.

Automated GIS Conversion:
The integration of a variety of appropriate technologies into the GIS conversion process resulting in improved quality, reduced project completion time and lower cost through the reduction of manual labor.

Scanning:
The process of converting a hardcopy document or map into a digital picture or image. The scanning operation produces unintelligent digital information called a raster image which serves as the basis for an automated conversion process.

Raster Image:
A digital picture resulting from scanning a document. This raster image is composed of an array of dots, or pixels (picture elements). Each dot represents the level of darkness, or grey scale, of the original document at that location. Raster images typically range in resolution from 200 to 500 dots per inch and may represent either black and white (binary) or full grey scale images with up to 256 levels of grey. For instance, a grey scale image of a 24 inch by 24 inch map at 250 dots per inch produces 36 megabytes of data.

Raster to Vector Conversion:
The process of identifying pixels which represent line work or graphics, separating these pixels from the background and converting them to a connected vector representation. This vector representation allows graphic information to be easily manipulated, edited, attributed and stored and is a basic component of a GIS. The raster to vector conversion process may occur either in a batch process, which requires no human interaction, or in an interactive process, in which an operator simply points to lines to be vectorized on a workstation screen and the system automatically follows, or vectorizes, those lines.

Interactive (Vector over Raster) Editing The use of a high resolution color graphics workstation to allow an operator to easily view vector graphics as an overlay on top of a grey scale image of a source document. This interactive editing station is a key ingredient in the automation of the conversion process, including vectorizing, attributing, land base correction, edge matching and data verification.

Orthophotograph:
An aerial photograph which has been corrected for geometric distortions. The resulting photograph is accurate to scale in both x and y directions and can be used as a photographic map of the area.

Artificial Intelligence:
The ability of a computer to make decisions which appear to require human reasoning. These decisions are made by

applying probabilistic rules that represent a given 'knowledge base' corresponding to a particular situation. Each of these rules, depending on its degree of correlation to the situation, is given a different weight in the determination of an answer to a problem.

Edge Matching:
The comparison of pairs of common linear features along a specified map boundary to create a single, joined feature.

Layer:
A 'structure' within a data base which contains individual features (or a combination of features and networks) which are logically related or associated by information type. A GIS database may contain as many layers as the user requires. Layers may be identified by number, name and description.

Hardware Technologies
Critical to the creation of the automated conversion process has been the development and integration of several key hardware technologies. The most important of these are briefly reviewed below:

High Resolution Grey Scale Scanners:
The first step in the automated conversion process is the scanning of source documents. Since the entire ADC process relies on the manipulation of digital images of maps and other documents, it is extremely important to make sure that an accurate representation of the documents be captured during this initial phase of the project.

Most scanners consist of two basic components: a sensing device which detects the amount of light reflected from a point or group of points on a document, and a transport mechanism which causes the sensing device to move in relationship to the document.

Most scanners today utilize a charged coupled device (CCD) as the sensing element and one of the following types of transport elements:

- continuous feed - the document is moved over the sensing device by pinch rollers
- flat bed - the document is laid flat on a table and held constant as the sensing device is moved over it
- drum - the document is attached to a drum while the sensing device moves across the drum as the drum is rotated

Drum scanners are typically both the most accurate and the most expensive, but are limited as to the size document they can handle, which depends on the circumference of the drum. Flatbed scanners are slightly less accurate and a little less expensive, and maximum document size is also limited to the size of the bed. Continuous feed devices are both the least expensive and the least accurate, and have the greatest flexibility in the size document they can handle, particularly in the document feed direction. Most scanners being purchased today are either continuous feed or drum type scanners.

Optical Disk Drives:
A 24"x24" document scanned at 200 dots per inch with 256 levels of grey produces 25 megabytes of data. A project consisting of 1 000 such documents therefore requires 25 gigabytes of image storage. Because of this massive storage requirement and the need to have very rapid access to all of the drawings which comprise a project, write once-read many (worm) optical disk technology has been critical to the development of the automated conversion process.

Optical disk drives utilize removable platters which can be taken out and replaced in much the same manner as floppy disks. Optical disk platters are available in two basic diameters: 12 centimeters and 12 inches. Each platter can hold from 300 megabytes up to 2.4 gigabytes, depending on the particular technology used, and these storage capabilities are continually on the increase. Each 2.5 gigabyte optical disk platter can therefore hold approximately 100 high resolution grey scale images. A project which consists of 1,000 drawings can be maintained on only 10 platters and, by utilizing multiple drives (or simply by switching platters as necessary), drawings from multiple projects-each consisting of thousands of drawings-can be easily accessed, manipulated and archived by an operator at a workstation.

Interactive (Vector Over Raster) Workstations:
Automated data conversion technology relies on the ability to manipulate very high quality raster images of maps, as opposed to sheets of paper. An operator must also be able to display vector information created from a map (or other sources) as an overlay to a raster image of a document. Thus, the development and integration of very high resolution and high speed graphics workstations has been one of the most critical elements in the ADC development process.

New display systems have very large internal memories (from 5 to 16 megabytes or more) to allow high resolution grey scale images to be quickly displayed, panned to any location and zoomed into to magnify small numbers and symbols. These systems also allow full grey scale images to be displayed, permitting an operator to easily view documents with varying shades of grey, scanned aerial photography and digital satellite imagery, with overlays of vector data. This allows vector data from one source to be easily compared to raster data from another source and for these documents to be viewed simultaneously, one over the other, for very precise manipulation and registration.

High Speed Dedicated Processors:
The analysis and processing of images requires very complex operations to be performed on very large data sets - remember, a 24"x24" grey scale image can produce as much as 36 megabytes of data. To reduce the processing times of specialized operations such as feature extraction and raster to vector conversion, high speed arithmetic array processors are employed. These processors allow the complex mathematical transforms required for vectorization and classification to occur between 10 and 100 times faster than possible on conventional, general purpose CPUs.

Without this type of processing power, it would be impractical to perform these operations in a high volume production environment in which thousands of documents are routinely converted.

Local Area Networks:
One of the key challenges involved in developing the ADC process has been adapting it to large volume production needs. Much of the work done by the major vendors of scanning and drawing conversion systems has been based on the one-drawing-per-operator concept. In other words, they were designed with the idea that one person would perform all of the conversion functions required on a single document before moving on to the next document.

This is not a practical approach for a large volume operation. Multiple operators must be able to work within a smooth production flow on very large, complex projects. This means that documents must be able to move automatically from one operator/workstation to another. And this requires moving tremendous amounts of information at very high speeds. A single drawing, with its associated files, might easily represent 30 to 50 megabytes of data. Thus to move just 20 maps through a process involving five different workstations (or processes) in a day requires the rapid transfer of about five gigabytes of data. On a typical day, a large volume conversion process may move as many as 100 maps, or 25 gigabytes of information.

The advent of local area networking (LAN) and cluster technology has therefore been a critical element in the success of the ADC process. LANs allow data to be moved from one processor to another at speeds of up to 1 megabyte per second. This means a drawing, as well as all of the information associated with it, can be available at any one of many locations in less than 60 seconds.

This technology has also led to the clustering of data. Centralized magnetic and optical storage systems can now be used without sacrificing rapid access by large numbers of workstations. In an ADC process, the LAN becomes the backbone of the operation by acting as the electronic 'conveyor belt', routing each document to the appropriate process at the appropriate time. As a result, there is no longer a need to manually move sheets of paper through the production process, and the movement of every drawing can be automatically tracked and relayed by the system.

The Process
The traditional conversion process can be broken down into five basic steps:

1. Landbase conversion,
2. Review and compilation of source documents (scrubbing),
3. Registration of source documents to landbase,
4. Digitization of graphic entities,
5. Building of attribute database for graphic entities,

Two additional procedures are not steps but, in an automated conversion process, take place continuously throughout the process:

- Quality control of both graphic and non-graphic information,
- Project and document management for the entire project.

These steps are described in detail in the following subsections, along with information on how they are being automated through the use of new conversion technologies.

1 Digital Landbase Conversion
There have traditionally been three ways to create a digital landbase:

1 Digitize the landbase directly from an existing hardcopy source.
Although these maps may be readily available, may be at the proper scale and are only moderately expensive, many existing landbases were created with poor ground control and cartographic standards. Thus, these maps may be very inaccurate and individual sheets may not tie together.

2 Purchase an existing digital landbase from a source such as the USGS or ETAK.
This data is generally readily available and very inexpensive when compared to other alternatives. On the other hand, landbases from these sources are often at a fairly large scale (1:24 000 or 1:100 000), may not contain the information required, or may not be available for the required area.

3 Create a new digital landbase from recent stereo aerial photography.
While this is very current and accurate digital landbase data and can provide significant details, including such things as driveways, sidewalks, utility poles and individual trees, it is also the most expensive of the three alternatives. To create a digital landbase for a single county from stereo photogrammetry could cost several million dollars.

Now, by integrating scanning, raster to vector conversion and interactive editing workstations, a fourth alternative is being developed. It combines the digitization of existing source maps and the use of aerial photography to provide the accuracy of aerial photography at a significantly lower cost.

The original hardcopy landbase maps are scanned and converted to raster images. Then these raster images are processed through raster to vector conversion software to separate the linework from the background and to automatically digitize the graphics. The graphics are also divided into individual layers based on line width or line symbology. This information is then reviewed and edited at an interactive editing workstation. This process significantly automates the digitizing of the existing landbase by eliminating the manual digitizing process. The main problem that remains is that, as mentioned above, the original landbase may not accurately represent the real world.

To correct this inaccuracy, orthophotos are produced from aerial photographs of the area to be mapped. These orthophotos are then scanned to produce a grey scale raster image. The vectorized landbase information captured from the original hardcopy landbase is then displayed on top of the orthophoto at a graphics edit station. By indicating common points such as road intersections or property boundaries, the vector landbase can then be automatically warped to fit the orthophoto. In addition, any information which does not appear on the original landbase, such as new roads, may be easily updated.

This new alternative is less expensive because it uses automatic vectorization, and more accurate because it rectifies the landbase to current orthophotography.

2 Review and Compilation of Source Documents (Scrubbing)

This process, which ensures that all information to be converted to the GIS is up-to-date and accurate, varies significantly from one project to the next. It is also often a much larger task than anticipated because it is frequently discovered that records have not been kept as current as had been hoped. Each drawing must be reviewed and compared to other maps, work orders and property and equipment records, meaning thousands of documents must be organized and handled by dozens of people. Then, to complicate matters, construction and growth alter the information recorded as it is being converted.

One way of dealing with this problem is to 'freeze' the records as of a specific date before conversion, perform the records updating and conversion, and the update the digital database with the modifications that occurred during this process. This makes the time required to complete the conversion critical: the quicker the conversion, the smaller the updating backlog.

Document management technology can significantly improve the management of and facilitate the handling of these thousands of documents. Each map or document is scanned and stored on optical disks before the scrubbing begins. Information about the type of document, the information contained on the document, and the geographic coordinates of the information contained on the document, are entered. The conversion system will then contain both a digital catalogue and a digital image of all documents, which may be on line and easily accessible to operators at interactive editing workstations.

Automated scheduling then routes specific documents to specific interactive editing workstations. This allows the scrubbing process to be managed through automated production control procedures. Changes or revisions are made through raster or vector editing techniques, rather than via laborious manual drafting. The status of the scrubbing process can be determined at any time and bottlenecks are easily identified and acted upon.

This approach is not usually economical when using a manual conversion system, since scanning all drawings before the scrubbing process simply constitutes an additional cost which is not readily recovered. On the other hand, if the entire conversion process is relying on automation through scanning technology, this approach implies no increased cost since all documents must be scanned and indexed as an initial step in the conversion process. By scanning the source documents before the scrubbing operation, the scrubbing has been integrated into the conversion process and automated the management, handling, manipulation and editing of the documents. Quality improves and both time and expense are saved. Moreover, post-conversion updating costs are also reduced, since the 'records freeze' period is far shorter.

3 Register Source Documents to Landbase

By this point in the conversion process, a digital landbase has been created and the source documents have been reviewed and updated. The next step is to register these source documents to the digital landbase. Traditionally, the information from the source documents is manually warped to fit the digital landbase by redrafting or by cutting and pasting the source information on the landbase while making necessary adjustments to register the two data sets. This may require the source documents to be manually redrawn and is an extremely time consuming and relatively inaccurate operation.

Another approach has been to utilize control points, such as section corners or other benchmarks, to warp the source data to the digital landbase through the use of warping software. This eliminates the need for re-drafting, but often provides insufficient registration since the warping required may vary significantly across a document and there is often limited control information available. For example, on one map the upper left quadrant may need to be stretched in the x-direction, the lower left may need to be shrunk in x, while the upper and lower right quadrants may require independent distortions of x and y. This kind of rectification will require a minimum of nine control points, and optimally 15 to 25. As a result, it is often impossible to completely rectify the source documents to the landbase using this method.

A third approach, using scanning and interactive editing workstations, is now being developed. The corrected digital landbase is displayed as an overlay on top of a grey scale raster image of the source map. The operator can then easily detect any distortions between the digital landbase and the source map. The operator then identifies pairs of points, one on the vector landbase and one on the raster document, which should be tied together. After choosing several pairs, an interactive non-linear warping operation occurs and the results are viewed by the operator. To 'fine tune' the registration, the operator may continue entering points until a satisfactory registration is achieved. This operation results in a set of control points which are then used to warp the source map to exactly fit the digital landbase.

Through this process, it is possible to easily and precisely register the source map to an accurate landbase, even when the distortions are very random. More importantly, this does not require any redrafting of the source map to fit the digital base. And finally, it requires no known control points to be identified on the source documents.

4 Digitize Graphic Entities From Source Documents
Now the graphic information on the original source maps may be digitized.

Traditionally, this has meant laying each sheet on a large digitizing table, entering control points to register the map to the table, and manually tracing over each line, point, or symbol to be captured. This manual digitizing process is very time consuming, tedious and error prone. The quality of the digitizing is limited by the operator's ability to consistently follow the center of a line. This accuracy problem is further complicated by the fact that the operator has no opportunity to compare the accuracy of the digitizing to the original map until he or she plots a copy and performs an overlay of the document on a light table. At this point errors are identified and the graphics must be redigitized.

Scanning, raster to vector conversion, automatic layering and an interactive editing workstation significantly automate this laborious process. Source documents have already been scanned for scrubbing and land base registration and are now ready to be converted from raster information to vector information, which may occur in either a batch or an interactive mode. The batch process operates in two phases: first the system automatically identifies graphics on the source map and separates them from the background image; then the centerlines of each graphic element are computed and converted to a set of connected vectors, or arcs. Artificial intelligence techniques are then used to automatically layer information into major categories, such as symbols, text, dashed lines, dotted lines or thick lines. This batch process provides the first level of intelligence to the data with no operator interaction and greatly increases the value of the data.

Raster to vector conversion may also be done at an interactive editing workstation by an operator, who simply points at the lines on the screen to be vectorized. This eliminates the tedious manual tracing operation required by manual digitizing.

The results of the raster to vector operation (either batch or interactive) is a set of graphic elements which are classified into major layers, such as text, symbols, hydrography, transportation or boundaries. This information can then be displayed on a interactive editing workstation on top of the grey scale image of the original source document.

The operator then groups graphic elements (arcs and points) into unique graphic entities, such as parcels, lakes, transmission lines, roads, etc. In this step, arcs which are required to represent more than one entity, such as both county and state boundaries, are not duplicated but simply linked to both entities. This interactive process can occur very rapidly by simply defining an entity and pointing to the graphic elements which are required to represent it.

The tedious manual digitizing operation is eliminated and the operator can easily compare the vector data to the original source document without generating a hardcopy plot. Graphic entities can be easily created and the duplication of graphics for coincident lines is eliminated. Most importantly, however, because automatic line following is utilized and because the operator has the ability to view the vector data on top of the original source map, digitizing errors are virtually eliminated.

5 Build Database For Graphic Entities
It is now necessary to add intelligence to the graphic entities. For example, a graphic representation of a road may have been created, but information such as width, material, number of lanes, number of accidents and speed limit is necessary. Assuming this information is not already available in digital form from other existing databases, it must be manually keyed in. Information may first be manually entered on data entry forms or it may be keyed in directly from the original source map. This type of tedious data entry operation is error prone and quality control is very tedious. Data is sometimes actually keyed in twice by independent operators to ensure quality.

Interactive vector over raster editing workstations can help here, too. When the attribute information appears directly on the original source map, this process can be automated as follows: an operator working at the interactive editing station enters an attribute definition loop in which the system displays the first graphic entity for which the attributes are to be entered; the operator is able to view the vectorized data on top of the original raster image so all attributes which were indicated on the original map are easily visible. The system then prompts the operator for each of the required attributes. As the attributes are entered, they are displayed on the screen next to the original attributes to allow the data to be easily verified. Once the information has been approved, the system pans to the next graphic entity to be attributed.

There is no need to use data entry coding forms or to key in information directly from the original source maps. More importantly, the accuracy of the information is greatly improved, since it can be verified and approved on the screen. The result is significant time savings and improved data accuracy.

Quality Control of Graphic and Non-graphic Entities
After all of the graphic and non-graphic information has been entered, the accuracy and completeness of the data must be verified. This has traditionally involved numerous data validation steps, the plotting and overlaying of graphics information and the comparison of attribute data lists to original source documents. Depending on the complexity of the data and the quality of the scrubbing process, data validation, review and correction may consume as much as 25 to 35 percent of the total conversion time. In some cases, the customer even becomes involved in this process, reviewing data and often finding it necessary to return large portions for corrections

Automated conversion can shrink the data verification process to less than ten percent of conversion time and eliminate the need for data to be returned for correction. This is due to the nature of the data creation process itself.

At each stage - scrubbing, landbase creation, graphic creation and attribute entry - two types of verification automatically occur as a result of the technology being used: first, an operator views the resulting data on top of the original raster image of the source document and, as each element is entered, it is compared to the original data and approved by the operator. Then, as the process continues, each operator must review the results of the previous operation.

Thus, quality control is no longer merely a final step; it is automatically built into the data throughout the conversion process. Of course, plots, listings and automated data validation checks are still used to double-check data quality, but the percentage of errors discovered during this final stage is drastically

reduced, resulting in higher quality data, increased productivity and further time savings.

Project And Documentation Management For the Entire Project

This is the continuous process of managing the entire conversion project, from before the first map is identified, through the final verification and loading of all data. Thousands of documents are handled hundreds of times by dozens of people. Literally millions of operations must occur to create the final data. The complexity of the process is in direct proportion to the complexity of the database being created. Large conversion projects have historically taken several years, and must deal with having to maintain and update drawings during an extended time period. The management of this complex operation is therefore a key requirement to its success.

In a manual process, manual procedures must be utilized to keep track of each drawing and each process. It is difficult to maintain accountability, identify bottlenecks and keep up-to-date information on a project.

Utilizing the automation tools now available can simplify this management problem, although no large conversion project will ever be a trivial task. Since all drawings are handled as digital images through an automated drawing management system, instead of as sheets of paper, the documents do not deteriorate through handling, drawing images are easily accessed and document routing is automatically controlled. This drawing management system automatically provides individual drawings and project status information to an automated project management system, allowing project status reports and productivity reports to be automatically generated. And problems and bottlenecks are quickly identified and corrected.

Results and Applications

This unique, proprietary process can be beneficial for a wide variety of conversion applications, ranging from complex county parcel projects to soils, timber stands or wetlands mapping, to electric, gas, and water and sewer utilities conversion.

There are instances in which automated conversion is not the most appropriate way to proceed, however. Significantly, it is economics, and not technological limitations, which dictate when manual conversion might be more advantageous.

Because of the set-up required for the automated conversion process, it may not be cost-effective to use this process to convert very low density maps, for example, a 40"x60" contour map with a circle in each corner to scan. In this case, very little data is being captured, although the entire document would have to be scanned and processed through the entire system. Thus, it may be more economical to simply manually digitize the four contours on a digitizing table.

In general, the larger and more complex the project, and the denser the data, the greater the benefits derived from the use of this automated conversion technology. An example of how this technology is being utilized on a complex project is currently underway for the Southwest Florida Water Management District.

In this project, the information contained on more than 600 flood insurance rate maps (commonly referred to as FIRMs) and 200 floodway maps, which are produced by the Federal Emergency Management Agency (FEMA) must be integrated and converted. Combined, these cover an area equivalent to about 220 USGS quads (approximately 9 500 square miles), making this one of the largest and most complex projects of its kind. The FEMA/FIRM panels provide the only District-wide flood plain information available, essential data for the model being implemented, which will ultimately assist in the identification of lands to be purchased by the District for water resource protection.

In addition, District personnel frequently refer to FEMA maps to answer questions from the public regarding the location of floodplain boundaries. Automating the FEMA panels also will make it easier to update and improve the original maps, as well as permitting the creation of custom flood plain maps, and FEMA is interested in using address-matching strategies to automatically produce lists of homeowners living within flood-prone areas.

But most of these FEMA maps were made in the 1960s and '70s by a variety of contractors using a wide range of methodologies, with no horizontal control. This, plus the fact that they are being used for purposes never dreamed of by those who produced them, (flood insurance rate maps are being used as the basis for plotting wildlife habitat patterns and soil recharge rates) lay the foundation for a host of conversion difficulties:

- The maps are not simply black & white. They are composed of a number of shades of grey, which are used to delineate different flood zone information, such as 100 and 500 year flood zones.
- The data is derived from two separate maps. The FIRM maps contain flood zone information, and the information from the corresponding floodway maps must be precisely tied to these maps to form the resultant polygon data set.

- None of these maps have horizontal control information. This control must be derived from the corresponding 1:24 000 scale USGS quad sheets. Which further complicates matters, since
- The firm and floodway maps range in scale from 1:6 000 to 1:24 000, and the floodway maps do not usually correspond exactly to a portion of a quad sheet. This means that up to four USGS quad maps may be required to develop horizontal control for a single floodway map.

Ultimately, all of these maps must be precisely edge-matched to form continuous information and then cut into quad sheet-equivalent tiles for use on the District's ARC/INFO GIS.

Despite the fact that most of these maps are considered by many to be "unscannable," the project is scheduled for completion in February, 1990. That represents a six-month turnaround time, half that specified by the Water District.

Parcel maps may also be successfully converted. Orange County, Florida needs to convert approximately 240 000 land ownership parcels contained on more than 1 750 parcel maps and encompassing about 500 square miles. Within each map, the parcels, lots, blocks, tie bars, hydrography, municipal boundaries, lot numbers and lot dimension features are being captured, layered and attributed. The entire project will be completed in only nine months. This project is the first major parcel mapping project in the nation to utilize this new technology - but certainly not the last.

In fact, another parcel project which fully utilizes the automated conversion process is just getting underway for the Northampton County (Pennsylvania) GIS. This project involves the conversion of 673 parcel maps (100 000 panels) and 51 unrectified soils maps, covering approximately a 376 square mile area. Its purpose is to create a database using parcel graphic overlays, annotation sheets, orthophotos and unrectified soils maps, as well as data on the assessor's digital database. All parcel, soil survey, municipal and district boundaries must be scanned, captured, rectified and registered to the County's orthophoto base map and converted into 1:4 800 tiles. Then the data will be output in ARC/INFO Export format.

Other soil map conversion projects have also benefited from this integrated, automated approach. The USDA, Forest Service needed to convert approximately 10 000 soils information polygons comprising the Olympic National Forest, with associated attributes from 91 sheet maps at a scale of 1:288 000. The resulting data files contain the polygon along with the major soil, minor soil and slope associated with it. All data was then converted to Washington State plane coordinates and edge matched. The final product was a continuous, real world soils database for the entire Olympic National Forest of approximately 2 800 square miles. This data was delivered in MOSS format.

Finally, oil and gas, one of the first sectors to take advantage of this new technology, has particularly appropriate conversion needs. More than 1 000 7.5 and 15 minute USGS quadrangles were converted for a major oil company's Corporate GIS. Four primary layers of data: hydrography, transportation, boundaries and points, were captured. Nineteen unique features were identified within these layers and the resulting data was fully topologically structured, converted to latitude and longitude coordinates and edge matched (regardless of the scale of the source maps). The result was an absolutely continuous real world database covering approximately 80 000 square miles. Significantly, the project was completed in just ten months and fewer than two percent of the maps were found to contain even a single error.

Conclusions

On December 17, 1903 at Kitty Hawk, North Carolina, Wilbur and Orville Wright got their flying machine off the ground for the first time. Although Orville was aloft for only 12 seconds, this was the birth of Aviation. Flying, however, did not become a more effective means of transportation than the automobile until several decades later, after an entire system of integrated technologies had sprung up around it. Similarly, scanning technology did not become a more effective means of GIS data conversion until an entirely new system, which integrates a wide range of technologies, was created.

Through the integration of these technologies, data is now of higher quality, people are more productive and projects are completed more quickly than anyone would have thought possible just a few years ago. But then again, in 1903, who would have ever thought Wilbur and Orville were not only getting us off the ground and across oceans in record time, but ultimately, all the way to the edges of the universe.

And now, through the creation of geographic information systems and automated conversion technology, we can improve the way we manage our small corner of that universe.

Appendix

Case Study #1

Automation of County Parcel Maps for the Orange County GIS

This project involved the conversion of more than 240 000 land ownership parcels contained on more than 1 750 parcel maps. The County encompasses approximately a 500 square mile area. Within each map, features such as parcels, lots, blocks, tie bars, hydrography, municipal boundaries, lot numbers, lot dimensions, etc., were captured, layered and attributed.

This was the first major parcel mapping project to use automated data conversion technology. As a result of this work, Orange County is experiencing better graphic quality and data accuracy than is typically produced by manual digitizing methods.

The Orange County GIS hardware includes: DEC VAX computers, terminals, peripherals and GPX/II workstations located at four major locations. The large scale data processor is a VAX 8850 and is connected with five departmental Micro VAX 3600 computers, all interconnected with very high speed fiber optic links in a government-owned network. Many DEC GPX/II and VAXStation 2000 workstations are also connected to the network using the Ethernet and DECnet protocols. The network represents a distributed computing network with a central map/database on the VAX 8550 with more than 5 gigabytes of on-line disk. Software includes Geovision Corporation's AMS (Advanced Mapping System) and GIS products, McDonnell Douglas's GDS CADD software, ORACLE and related products for relational data base management and SPSS for statistics and business graphics.

All data was translated from internal digital files to Intergraph SOF files and delivered on magnetic tape. Data checkplots were also supplied. The entire 500 square mile project was completed in just 10 months, all original costs and schedules were met and not a single data error has been reported.

Over the next few years, Orange County will be mapping additional layers.

Case Study #2
Pilot Project for Parcel Map Conversion Prince William County, Pennsylvania

This project required the conversion of newly recompiled parcel maps and delivery in ARC/INFO Export format. The source re-compiled maps were colored pencil on mylar maps.

The County had been manually converting their re-compiled parcel maps. In an effort to speed up completion of the parcel database, the County requested a pilot study be conducted to determine the best method for automation. This pilot project consisted of four 1:2 400 scale parcel maps. Three of the maps required that a polygon coverage be created from all parcel lines. The fourth map was provided with a polygon coverage of all parcels and with all text on the map. The data was converted to the Virginia Coordinate System using 1983 international feet coordinates.

The coverages were clipped to a box having the four tics as corners. All four maps were edge matched to assure continuous data across map sheet borders. The digital data was supplied to Prince William County in ARC/INFO Export format on nine track magnetic tapes.

CASE STUDY #3
FEMA Mapping Southwest Florida Water Management District

This project is significant because it involves the creation of a database by combining data from several sources, because it is being delivered to the client in ARC/INFO Export format, and because control information for the FEMA maps is being derived from a third source.

A 9 500 square mile, 15 county area in southwest Florida is covered by this project, making it one of the largest and most complex conversion projects of its kind. The maps to convert are 807 FEMA FIRM and Floodway maps, at scales of 1:12 000, 1:144 000 and 1:288 000.

The flood zones, hazard zones, political areas, river mile markers and reference marks, and hydrography are the layers, or coverages, captured. Thirty-four unique attributes are assigned to the five coverages. The coding scheme for the project includes a polygon, line, link and network coverage. This allows for maximum flexibility for spatial analysis.

Since the FEMA maps do not contain control information, a third source for control is necessary for conversion. Thus, all FEMA maps are reviewed with corresponding USGS quads for location of coincident features. Section corners, street intersections and hydrologic features are being used to determine control. The digitized linework is being transformed into Universal Transverse Mercator meter coordinates using control information derived from USGS quadrangles.

There are four key conversion difficulties associated with this project:

- The maps are not simply black & white. They are composed of a number of shades of grey, which are used to delineate different flood zone information, such as 100 and 500 year flood zones.
- The data is derived from two separate maps. The FIRM maps contain flood zone information, and the information from the corresponding floodway maps must be precisely tied to these maps to form the resultant polygon data set.
- None of these maps have horizontal control information. This control must be derived from the corresponding 1:24 000 scale USGS quad sheets.
- The firm and floodway maps range in scale from 1:6 000 to 1:24 000, and the floodway maps do not usually exactly correspond to a portion of a quad sheet. This means that up to four USGS quad maps may be required to develop horizontal control for a single floodway map.

Ultimately, all of these maps must be precisely edge-matched to form continuous information and then cut into USGS 7.5 minute quad sheet-equivalent tiles for use on the District's ARC/INFO system. In addition, the data from the FIRM and floodway maps are being combined. All the quadrangle maps are being edge matched to produce a seamless, topologically correct coverage.

The final data files are being converted to ARC/INFO files. The data is then generated to create line and point coordinate files, and built and appended to combine adjacent coverages. Finally, new coverages are formed in increments of USGS quad boundaries using CLIP. All data will be delivered to the District in ARC/INFO Export format by January 1990, which represents a six month completion time.

By February 1990, the Water Management District will have the data required for the FEMA layer of data needed for the GIS, and FEMA will have digitized maps that it can easily update and, in the future, to which it can tie street names and other pertinent information. This means that banks and insurance companies will have better data on which to base mortgage decisions and insurance rates, and city planners will have accurate flood and water management information at hand when issuing building permits and establishing building codes.

Case Study #4
Automated Conversion of Topographic Maps for District GIS Applications
Southwest Florida Water Management District

This project is significant because of the nature of the source documents: aerial photo contour maps. The map sheets contained 2-foot contours and spot elevations displayed on top of full grey scale aerial photography. This type of original is typically considered impossible to convert via automated processes. However, because of the use of unique grey level scanning capabilities,it was possible to apply the benefits of automated data capture to this project.

Contours were digitized from mylar separates of 1:1 000 USGS contours. All 2-foot contours, spot elevations and associated Z values were captured to an accuracy of 0.004". The plots also exhibited the scale of the plot and maximum and minimum real world values computed for the data captured. The data was converted to UTM coordinates and delivered in the USGS DLG3 optional format on 9 track tape at a density of 6250 bpi for use on an ARC/INFO system. In addition, a final check plot on 4 mil double matte finish film was provided for each sheet.

This project covered an area of approximately 600 square miles and was completed without a single digitizing error being reported.

Case Study #5
Production of Digital Cartographic Base Maps from USGS Quadrangles

This project involved the automated conversion of USGS 7.5 minute, 1:24 000 scale quadrangles for use in the ITT Rayonier, Inc. Southeast Forest Resources PC ARC/INFO system, The database covered approximately 100 000 acres of ITT Rayonier property in five Georgia counties.

Five data coverages were created from the quadrangles: transportation, hydrography, political, point, and section coverages. Within these five coverages, forty-three unique features were identified:

Transportation
- Four lane or divided highway
- Primary highway, hard surface
- Secondary highway, hard surface
- Light-duty road, hard or improved
- Unimproved road
- Jeep trail
- Railroad
- Abandoned railroad
- Tram road
- Airport
- Powerline
- Telephone line
- Pipeline
- Map neatlines

Hydrography
- Intermittent drainage
- Rivers
- Perennial drainage
- Ponds, lakes, reservoirs
- Bays, oceans
- Map neatline

Political
- State line
- County line
- City boundary

Point
- Church
- School
- Police station
- Cemetery
- Hospital
- Lookout tower
- Fire station
- Boat ramp
- Forest Ranger station
- Radio tower
- Towns, villages
- Benchmark elevations
- Gates

Section
- Township or range line
- Section line

The digital database was created via an automated conversion process. All graphics, polygons and attributes were formed there. All data was converted to Universal Mercator coordinates. Each map sheet was coordinate edge matched, within each respective layer, with adjacent map sheets to provide a contiguous database.

This data was then translated into ARC/INFO format. All coverages were cleaned and built. Two copies of the quad sheets were delivered to ITT Rayonier. Each quadrangle was delivered as an individual 7.5 minute map, as well as edgematched and appended to form coverages per ITT Rayonier specifications. The data was delivered in PC ARC/INFO format on high density 5.25" floppy diskettes.

The 21 quads were delivered in 60 days.

Case Study #6
Automated Conversion of Soils Maps For the USDA - Forest Service, Olympic National Forest

This project required the conversion of approximately 10,000 soils information polygons with associated attributes from 91 map sheets at a scale of 1:24 000. The resulting data files contain the soil polygons with the major soil, minor soil and slope associated with them.

To produce 91 digital map files of soils information polygons in MOSS format, six crucial functions took place:
- lines were captured to a specified degree of accuracy,
- the linework was edited,
- polygons were attributed with soils information,
- the attribution was edited,
- MOSS files were written to an unlabeled tape.

A very brief process description follows, describing how each of the above functions was addressed.

After project setup, each mylar was scanned at 100 pixels per inch, which provides an accuracy to within 0.01 of an inch. An automatic raster to vector process identified virtually all linework and polygon intersections on the maps and, by appropriately setting parameters, was able to ignore the annotation. A file of unattributed line segments was produced.

At the interactive edit workstation, the operator reviewed all linework by viewing the digitized vectors on the screen with the scanned image in the background. Line segments and intersections were easily added or modified. The editor then formed polygons from the line segments by merely selecting the desired segments of the polygon. After all polygons were so determined, the system looped through each polygon, prompting the editor to enter the soils information attribute, which was read by the operator from the background image. The polygon formation was assured by the operator during this process, and the typed attributes (in the proper three component/slash format) appeared on the screen for easy checking.

The registration tics and their values were then entered at the workstation. The polygon endpoints on the edges of adjacent maps were represented on the screen relative to the current map. Each endpoint was matched with an endpoint from the current map based on location and matching attributes, and this was indicated visually on the screen. Any unmatched endpoints were easily identified and resolved. At the end of interactive editing, the digitized data for the map consisted of clean, accurate linework in a polygonal structure, attributed, and with pre-reviewed edge matches to adjacent maps. All data had been edited and coordinates were in an internal system.

A batch process then converted the internal coordinates to Washington Zone 4601 state plane coordinates. Another batch process performed the actual edge matching of the endpoints on adjacent maps. Plots and listings were produced for the second stage of quality assurance. This second stage re-verified that the plotted data overlaid the original maps, that polygons were properly formed with correctly entered soils information, and that the data on adjacent maps all merged correctly. Any errors were rectified at the interactive edit workstation.

After each map was verified as correct, all data was converted to MOSS EXPORT format files. The MOSS files were written to an unlabeled tape, at 1600 BPI, in ASCII with a blocking factor of 8192. The final product was a continuous real world soils database for the entire Olympic National Forest, approximately 2,800 square miles.

Case Study #7
Automated Conversion of 1,100 USGS Quads for use on a Corporate GIS

This project, completed for a major U.S. oil corporation, required the conversion of approximately 1 100 7.5 minute and 15 minute USGS quadrangles. Four major layers of information were captured from the quadrangles: hydrography, transportation, boundaries and points. Nineteen unique features were identified within these layers. The resulting data was fully topologically structured, converted to latitude and longitude coordinates and edgematched (regardless of the scale of the source maps). The result was an absolutely continuous real world database covering approximately 80 000 square miles.

The data was structured per USGS DLG standard and delivered in a client-specific format.

Approximately 1 100 digital files on 9-track tape, as well as final checkplots, were delivered in approximately ten months, and fewer than 0.5% of the maps were found to contain even a single error. The original schedule called for the completion of 1020 maps in nine months. This goal was met. An additional 50 quadrangles were added during the final months of the project, and an additional month was added to the delivery date. The cost of the project remained as budgeted.

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GIS for Forest Information Management: A Case Study for the Cloquet Forestry Center, University of Minnesota

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Abstract
As the principal forestry field station of the University of Minnesota, the Cloquet Forestry Center (CFC) serves as a focal point for forestry research, instruction, and extension and continuing education in the state. Research at the CFC began in 1911, and efforts to utilize a GIS to integrate the unique data and information sets collected at the center were initiated in mid-1989. Planning for GIS acquisition and implementation has involved several phases, including a user requirements analysis, data and map inventory, and database design and development. Given the goal of establishing a practical, operational GIS for the field station, our paper discusses design concerns and implementation plans for GIS development. Introduction

Introduction

A geographic information system (GIS) is a hybrid database management system that uses both cartographic and associated attribute information to create a digital (or analog output) map of an area or location. By allowing incorporation of map information with the corresponding attribute information, a GIS can provide a very complete description of a geographic area. GISs are often conceptualized as a series of data or map layers, such as soil, hydrology, and wildlife maps, for a specific location.

Linking spatial features to their associated attributes requires strict organization of the data. GIS data structures are complex since they must include information about geographic entities with respect not only to attributes, but also to location and topological relationships. Essentially, the topological and spatial aspects of GISs distinguishes them from other types of data bases.

Yet, while GISs provide powerful, flexible data management and analysis capabilities, GIS projects can and do often fail due to insufficient planning (see, for example, Montgomery, 1989). The goal of this paper is to describe the planning process used in the initial phases of a GIS project, and to draw general conclusions from that process that will be useful to others who are considering a GIS for forest information management. The first part of the paper describes user involvement in the project through a requirements analysis. And second, a linear programming problem is formulated in order to prioritize data input and to assess benefit/cost sensitivity.

Overview of the Cloquet Forestry Center

The Cloquet Forestry Center (CFC) serves as field campus for the College of Natural Resources at the University of Minnesota. Forest types on the CFC consist of about two-thirds upland red, white and jack pine, spruce-fir and aspen-birch. Lowland forest types include black spruce, tamarack and northern white cedar. The Center's forest management is geared to maintaining the forest types and ages needed for teaching, research and extension and continuing education. Increasingly, specific annual and project-based plans frame the actual land treatments which then provide the basis for development of stand records; and thus, the primary database from which a GIS could emerge.

Maps and other geographic records are fundamental to the continued manipulation of the forest and especially to the orderly and articulate expression of historical activities. The objectives of a GIS for the CFC are:

1 provision of a uniform record keeping system for documenting, storing and displaying land treatments;
2 service as a tool for locating prospective research, teaching and demonstration site opportunities;
3 demonstration of the capabilities of a GIS to the users and clientele of the CFC, the Minnesota Extension Service, and the College of Natural Resources; and
4 serve to complement the teaching program at the Center and expand graduate research and teaching capabilities.

Essentially, through GIS technologies the CFC has the potential to greatly improve upon it's historical missions of research, teaching, and demonstration.

User Requirements Analysis

The Cloquet Forestry Center requires accurate map and attribute information to support its mission. The current status of the information at the CFC is such that data are collected at different map scales on many different bases, and are not systematically cross-referenced by geographic location. The critical task in trying to implement a GIS for the CFC is the design of the integrated map and attribute database. In turn, the key element in that design process is a user requirements analysis (URA). A URA is essentially a detailed study of the needs of potential system users. The URA defines the critical user needs for the system and allows development of a comprehensive assessment of the analytical capabilities and products required by the users of the GIS. The URA process as applied to the CFC was derived in part from the U.S. Geological Survey (1988), and consisted of four steps:

1 mailing a GIS educational primer,
2 a map and tabular data inventory,
3 user identification and interviews, and
4 database design and development.

One very effective component of the URA process was the use of the educational primer on basic GIS concepts. Since many users were unfamiliar with GISs, the primer was made available prior to the interview in order to develop or advance the user's level of understanding of GIS capabilities and possibilities. Thus, interviewees could better respond to questions about GIS needs and priorities.

Data Inventory

An inventory of the available map and tabular information for the CFC was conducted. Samples from the inventory lists are presented in Tables 1 and 2. The purpose of the inventory was to identify the map themes, scale, major features, updates, and the base material. This inventory information provided a useful reference that interviewees could react to. Map and/or tabular information inadvertently omitted from the inventory was also added as it was identified by users.

User Identification and Interviews

Identification and questioning of users is important to the ultimate success of a GIS project because user input generates the information about what exactly the GIS should contain and the questions or types of questions the system should be capable of evaluating. The individuals contacted for this effort represented a broad range of interests within the field of natural resources, including harvesting, forest mensuration, silviculture, management, hydrology, wildlife, genetics, and remote sensing. Users were also classified into two categories: 1) system users; those most likely to have direct contact with the system's hardware and software components, and 2) end-users; those who would most likely have little or no contact with the system, but would require the products that the system could produce. A clear majority of the users were identified as end users. This information is important in defining future system installation and training needs.

Meeting the user needs is an important step in the design and evaluation of a GIS and is a direct outgrowth of the

Table 1

Attribute	Vegetation1	Vegetation	Planting Regeneration
Scale	1:7920	1:7920	1:7920
Author	Severs	Severs	N/A
Date	1977	1977	1977
Revisions	1982	1988	1977
Projection	None	None	None
Material	Mylar	Paper	Paper
Size	16x24	16x24	19x24
Update Schedule	N/A	Yearly Update	Annually
Attributes	Species, Size, Density	Species, Size, Density	Year, Planting Number

Table 2

File	File Attributes
Research Records	Area, Stand, Compartment, Purpose, Title, Objectives, Researcher, Identification Number, Research Starting Date, Proposed Research Completion Date, Actual Research Completion Date, Preparer, Plot markers, Research conclusions
Regeneration Records	Remarks, Project, Area, Stand, Compartment Number, Purpose: research-teaching- demonstration-management, Soil Type, Site Index, Site Preparation Method, Date Preparation Took Place, Regeneration Method: Natural-Planting-Seed, Species 1, Age of Species 1, Source of Stock for Species 1, Origin of the Seed Source for Species 1, Planting Method for Species 1, Acres Planted for Species 1, Total Number of Trees for Species 1, Number of Trees per Acre for Species 2, Age of Species 2, Species 2, Design: map of layout, Species 2 Stock, Source of Stock for Species 2, Origin of the Seed Source for Species 2, Planting Method for Source 2, Total Number of Trees for Species 2, Number of Trees per Acre for Species 2, Date Planted, Seeding Method, Pounds of Seed, Plant Per Acre, Stocking A, Volume per Acre A, Stocking B, Volume Per Acre B, Units, Preparer, Date Prepared
Harvesting Records	Require, Remarks, Project, Area, Stand Number, Compartment Number, Purpose, Operator, Starting Date, Ending Date, Harvesting Type: thin-clearcut-shelter, Acres, Sale Method: bid-oral-negotiated, Total Appraisal, Total Sale, Preparer
Treatment Records	Project Number, Treatment Number, Compartment Number, Stand Number, Age, Basal Area Per Acre, Trees Per Acre
Production	Project Number, Species, Product Records

URA. In order to systematically identify these needs, a five-page questionnaire was designed. Questions were arranged into four sections, one each for spatial information, tabular information, the interaction between the spatial and tabular information, and a final section designed to address the general information needs of the CFC.

During the interviews users were shown the map and tabular information that had been compiled during the inventory phase of the URA. These matrices of map themes and tabular information were examined by the interviewees and information that users could improve upon or add to, such as information concerning data relationships, were added to the inventory matrix. This matrix form was especially useful for cross-referencing data with user needs. Interviewees also identified the scale and accuracy standards for mapped data. Potential administrative problems concerning data input were also averted by having users identify the typical analysis procedures that they perform, and the periodicity of database updates required.

An important but intangible part of the URA is involving users in the development of the system and making them realize that they play an important role in the ultimate success of the system. Developing a sense of user responsibility helps to insure that the data required to drive the applications are properly maintained and updated. This type of "user responsibility approach" should be included in any URA.

Compilation of Interview Information

The spatial themes listed in the inventory were rated by the interviewees in terms of use, with one being the most-used spatial theme and five being the least-used theme. This information was compiled and an inverse weighting scheme was applied in order to identify the most critical themes. Figure 1 shows, for example, that the vegetation map was rated as the most important map theme by seven of the interviewees. Figure 1 depicts results from applying a weighting procedure to all map themes and sorting them into descending order. This graph clearly shows three distinct levels of ranked importance, with the most critical map themes identified as vegetation, topography, roads and soils. Of secondary importance are vegetation history and understory vegetation.

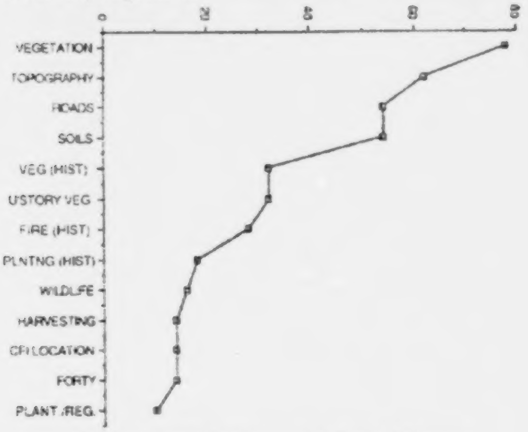

Figure 1. Rank Importance of Spatial Themes

Finally, users posed typical questions and situation statements that they believed a GIS should be capable of addressing. This led directly into a discussion of the datasets necessary to address critical research, teaching, and extension issues on the forest. Although the URA interviews and ranking scheme showed the most important single map themes, it did not account for map interrelationships, or for the composite or multi-map products that might be generated from single thematic maps. Addressing these issues and trade-offs is the focus of the next section of this paper.

Database Analysis Using Linear Programming

As a GIS database is developed, trade-offs between costs of data input and benefits derived from single and multiple map products must be assessed in order to minimize costs and maximize the efficiency and utility of the database. Budget constraints often limit the number of data sets that can be initially input. Yet, since GISs allow for the derivation of additional map layers from the combination of existing map layers, map themes that could be used to derive additional maps should be a priority in the initial phases of database development.

Data capture of the associated tabular and spatial information is typically the major cost in the implementation of a GIS, accounting for as much as 80 percent of the start-up costs of the system (Blakeman, 1987). Thus, applying a systematic method for identifying the best combination of individual themes, for both their intrinsic value and for deriving multi-map information, can be beneficial to system developers who must work within a specified budget.

Problem Description

The central planning issue is not only deciding which data layers to include in the system, but also identifying how database budget constraints can be used most effectively. In order to assess these constraints, an assignment or ranking of multi-map data theme priorities must be made. The goal is to include those data layers or themes which provide the greatest benefits to various users, while keeping the database development costs within the specified budget.

Several alternatives to solving this dilemma do exist. Prioritizing the multi-map themes and then entering the needed data themes for the corresponding multi-map information is one alternative. However, this alternative ignores the costs involved in creating the database and therefore does not truly maximize benefits within a specified budget level. While this technique allows identification and input of important information for producing multi-map products, it also results in an inefficient use of funds.

Another alternative would involve defining a budget level with which to build the database from prioritized individual maps. One problem associated with this approach is that the database may then be developed without the combination of map themes needed to produce multi-map products. This scenario could develop if system planners moved directly from the URA into database development.

Economic decision tools such as cost-benefit analysis or marginal analysis could also be applied to this problem. While these two approaches seem logical, there are several issues that make their application problematic. First, since single themes are used by several multi-map products, allocating benefits to themes or costs to products can be troublesome and arbitrary. Second, the value of a theme or the cost of a product depends entirely upon which other themes are already included in the database.

Linear programming (LP) is an analysis technique which shows a great deal of promise for solving these problems. Linear programming requires the specification of an objective function and a set of constraints which are linear combinations of "decision variables". The formulation of an LP problem provides flexibility in defining the constraints involved in the database decision problem, and minor modifications in the formulation allow sensitivity analyses to be performed easily and quickly (see, for example, Prisley et al., 1988).

Model Formulation

The linear model derived from the URA consists of fourteen decision variables (A-G, and D1-D2) and three types of constraints (each is defined below). The purpose of the model is to maximize the benefits of the multi-map products within the confines of both the allowable budget constraint and the single map theme combination constraints. The linear programming software package used to evaluate this LP problem is LINDO (Schrage, 1986).

The basic analysis technique consisted of multiple LINDO runs with the same budget constraint. During each of these runs decision variables not in binary form were identified and the decision variables were then set to zero for one run and to one for the next run. The process was repeated until all of the decision variables were in a binary state. This effectively dictated that maps were either digitized (one) or not digitized (zero). This process is called branch-and-bound (Taha, 1987), and by forcing the decision variable into a binary (zero or one) condition, readily reveals the maximum objective function value. Since the purpose is to maximize, the run with the highest objective function value is ultimately selected as an optimal solution.

The objective of this LP exercise is to maximize the benefit derived from map themes entered into the database. The coefficients for the multi-map decision variables were derived from the URA. Benefits were ranked from four to ten, with ten being the most important multi-map product, again as identified via the URA. These benefits were used as the values of the coefficients for each respective multi-map product (labeled A-G) in the objective function. The formulation of the objective function is:

$$\text{MAXIMIZE: } 10A+9B+8C+7D+6E+5F+4G$$

Where the decision variables A through G represent the following multiple map themes:

A: If 1, produce multi-map product A; if 0, do not produce multi-map product A (Harvesting map product)
B: If 1, produce multi-map product B; if 0, do not produce multi-map product B (Road construction map product)
C: If 1, produce multi-map product C; if 0, do not produce multi-map product C (Compartment accessibility map)
D: If 1, produce multi-map product D; if 0, do not produce multi-map product D (Compaction map)
E: If 1, produce multi-map product E; if 0, do not produce multi-map product E (Vegetation change map)
F: If 1, produce multi-map product F; if 0, do not produce multi-map product F (Fire Effects map)
G: If 1, produce multi-map product G; if 0, do not produce multi-map product G (Continuous forest inventory map)

Again, note that the decision variables (maps A-G) can be generated only from the individual map themes ranked in the URA (see Figure 1).

The objective function was subject to three sets of constraints. The first set of constraints identified the data themes to be digitized and the resultant multi-map products that could be generated from those themes.

The second constraint prevented subsets of the multi-map themes from being excluded from the database if the primary set is included. An example is multi-map theme A in which single map themes D1, D2 and D3 are included in A. Map B is a subset of A since it includes individual map themes D1 and D2; therefore if multi-map A can be created then map B can also be generated. By using a less-than-or-equals-to constraint, including map A in the database does not dictate that map B must be included separately (i.e., D1 and D2 would not have to be re-digitized in order to yield map B). Therefore, this second set of constraints eliminates the chance of not being able to generate a subset of a multi-map product if that multi-map product is already included in the database.

The third and final constraint is the budget level, which sets a limit on the amount of funding available for building the database and which essentially prevents costs from a multi-map/subset map trade-off (see the second set of constraints) from being added to the total costs. The coefficients for the decision variables are taken to represent the costs of producing a map product.

Interpretation

A budget level less than the sum of the total estimated single-map digitizing costs was used in the first run of the model. At this budget level, trade-offs between single and multi-map themes would occur. This prevents a trivial solution from being derived, and is a reality in terms of funding levels typically available for database development. Once an optimal solution was found using the branch-and-bound, the following conclusions were drawn.

The coefficients of the objective function (derived from the URA) were found to have a broad range of sensitivity. In fact, LINDO output showed that weighting the multi-map products by their respective rank resulted in little or no change in the final solution.

The total budget level itself appeared to be the most important constraint. The right-hand side (RHS) ranges in the budget constraint showed that the budget level could be increased by up to 23 percent without affecting the number and selection of multi-map themes to be digitized. Four of seven multi-map themes were included in the optimal solution. Conversely, the RHS could be decreased by only one percent without affecting the result.

After analyzing the coefficients assigned to the multi-map decision variables, it was determined that the model incorrectly defined the number of multi-map products that could be produced. Since the total cost of digitizing all of the necessary single map themes exceeded the budget level, costs for producing multi-map themes from single map themes were systematically underestimated. However, given that all costs were underestimated, the direction of change of model results, which was not evaluated at this time, can be expected to be consistent with increased costs. The sensitivity analysis suggested that, in fact, budget levels could be increased by over 20 percent without providing for the addition of any multi-map themes. A more systematic treatment of the trade-offs resulting from these changes is needed.

It can be seen from the LP model that database benefits can be examined and enhanced if an appropriate set of single map themes can be defined. Clearly, an iterative methodology like LP is needed in order to evaluate sets of database scenarios.

Conclusions and Recommendations

A GIS truly can provide numerous advantages for handling the data collected not only at the Cloquet Forestry Center, but for other forest management situations as well. GISs will not only enhance data management, but will also serve to demonstrate the capabilities of GIS techniques for forest management and planning. Additionally, a system may complement and expand research and teaching opportunities. Given both a multi-dimensional mission and a need to process a wide variety of data, a carefully structured approach was used in planning for GIS acquisition and implementation for the CFC. Our goal in presenting this paper is essentially to suggest that URA's and other planning tools are essential to the development of a successful GIS. As a result of this exercise, conclusions can be drawn regarding the conducting of a URA and also the use of LP for defining data input priorities.

One component that was critical to the success of the URA was the use of a GIS educational primer. This primer was part of an overall approach to planning that initiated and maintained a "user responsibility approach." Indeed, keeping both types of users actively involved in the project is very important. The primer itself helped uninformed users (typically end users) understand the capabilities afforded by GISs. Thus, users were better able to identify their needs and place them in an appropriate context. Also, classifying users as either system or end users can help strategic planning for future training and education needs.

Following completion of the user interviews, some suggested improvements to the interview process might include: 1) map and attribute inventories presented to the interviewees should contain only essential themes. Fewer choices may help to avoid overloading the interviewees, resulting in less confusion and in more key needs being expressed; 2) use an effective balance of open and closed-ended questions. This would allow unstructured input while focusing attention on key questions; 3) share compiled questionnaire/survey data with interviewees and include a section that encourages additional comments. This reinforces the importance of user involvement in both planning and in operational system use.

Linear programming provided a systematic method for identifying the best combination of individual themes, for both their intrinsic value and for deriving multi-map information, that should be entered into the GIS database. While difficulties arose in trying to estimate map production costs, the sensitivity analysis suggested reasonable budget level ranges. Furthermore, the single map themes needed to generate multiple map themes included in the LP solution were consistent with the priorities uncovered via the URA. Thus, at a minimum, the LP effort did help to formulate a reasonable, consistent database design.

In conclusion, many phases of GIS evaluation, procurement, installation, training and use can be predicated on a carefully conducted user requirements analysis. As GISs become increasingly prevalent and available to foresters, strategic planning issues will become central to the ultimate utility of this new and expanding technology.

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Session F7
Technical Issues in Remote Sensing

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Digital Orthophotography - A New GIS Tool
John Thorpe, Analytical Surveys, Inc.

Mapping the Land and Forest Types of Canada at Very Small Scales Using NOAA Imagery
Joe Lowe, Forestry Canada

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The Compact Airborne Spectrographic Imager: A New Digital Remote Sensor

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Abstract
Many applications of remote sensing technology in forestry demand higher spectral resolution than that available from aerial photography or current satellite sensors. Answering the demand is a new generation of instruments called imaging spectrometers. The Compact Airborne Spectrographic Imager (CASI) is a newly developed imaging spectrometer designed for aircraft or laboratory operations. This paper describes the CASI and presents examples of high resolution spatial and spectral data from a airborne mission over a forested area.

Introduction

Many applications of remote sensing technology in forestry demand higher spectral resolution than is currently available from aerial photographs or current satellite sensors. High spectral resolution aerial photography is possible but it is difficult and expensive to utilize in an operational environment (Ahern, 1988). Present satellite sensors provide inexpensive coverage of large areas but their limited spectral capability is not yet sufficiently detailed or accurate enough for condition and resource monitoring for intensive forest management (Battrick & Rolfe, 1986). A new generation of airborne sensors called imaging spectrometers has been developed that answers the need for high spectral resolution imagery.

One of the first imaging spectrometers, the Fluorescence Line Imager (FLI) was built for the Canadian Department of Fisheries and Oceans by Moniteq Ltd. of Toronto and Itres Research Ltd. of Calgary (Borstad et al., 1985). Although originally designed for ocean applications the FLI has been used for several imaging missions over forested areas (Rock et al., 1988). Building on their considerable experience with charge-coupled devices (CCD) imagers (Anger et al., 1987) and on Borstad Associates Ltd.'s extensive experience with the FLI and high resolution spectroscopy, Itres Research Ltd. has developed a second generation imaging spectrometer called the Compact Airborne Spectrographic Imager (CASI).

Description of the Compact Airborne Spectrographic Imager

The CASI was designed to meet the needs of the scientific community. These needs are to provide visible to near infrared digital imagery with high sensitivity, high spectral resolution and a wide dynamic range, to be compact and easily transportable, to be easily mounted in a variety of small aircraft, to be simple to operate, and most of all, to be of low cost (Babey and Anger, 1989).

The CASI is a pushbroom imager that utilizes a reflection grating and a two-dimensional charge-coupled device (CCD) array (Figure 1). The array is illuminated so that across-track spatial information is gathered in the long dimension (612 elements) and spectral information in the short dimension (288 elements). The spectral range is approximately 423-946 nm. with an individual element resolution of 1.8 nm. Spatial mode image data is acquired by 578 of the 612 elements, while the remainder receive dark signal and other diagnostic data. Table 1 summarizes the CASI's specifications.

The CASI records data in two fundamentally different fashions, referred to as imaging or spatial mode and multi-spectrometer or spectral mode (Borstad and Hill, 1989). In spatial mode, the CASI acquires data much the same as other pushbroom scanners, with the exception that the CASI allows spatial bands to be formed under software control. This means that the width, spectral position and number of bands can be specified during or prior to a flight mission. In, multi-spectrometer, mode the CASI is unique from other imaging spectrometers.

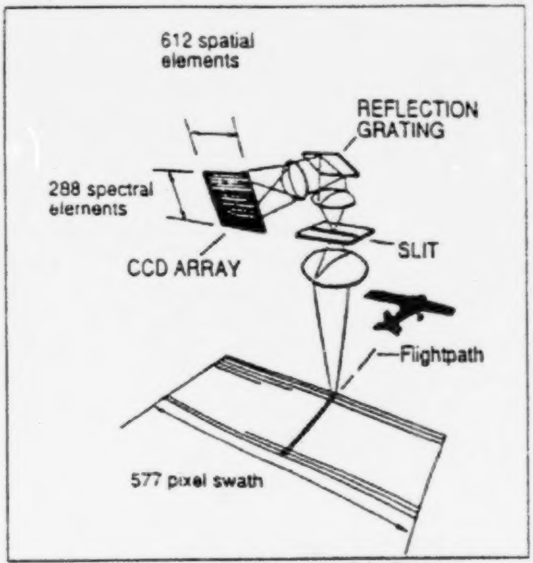


Figure 1. Conceptual diagram of theCompact Airborne Spectrographic Imager

Table 1. Compact Airborne Spectrographic Imager (CASI) Specifications

FIELD OF VIEW	40°
SPECTRAL RANGE	423 to 946nm
CROSS TRACK	1.3 mRad
SPATIAL RESOLUTION	(578 spatial pixels)
SPECTRAL RESOLUTION	1.8 nm
SPECTRAL BANDS	Up to 288 non-overlapping bands
SCAN RATE	Up to 50 lines/second
DYNAMIC RANGE	2 bits on chip, 16 bit via band summation
RECORDING	Digital cassette tape, 1.1 Gigabyte capacity,240 KB/s maximum recording rate
MASS	55 Kg
POWER	10V 2.5A

As the name multi-spectrometer suggests, the CASI is able to operate as several spectrometers at one time. Presently, under software control, the CASI can perform as a total of 39 separate spectrometers. What distinguishes the CASI from other imaging spectrometers is that it simultaneously acquires a mono chromatic spatial image, called the track recovery image, to which extracted spectral data are co-registered (Borstad et al., 1989). For a further description of the CASI refer to papers by Borstad and Hill (1989), Borstad et al. (1989) and Babey & Anger (1989).

CASI Data Translation

The CASI records data as 16 bits and stores the data digitally on 8mm video cassette tapes. The recording device is a EXABYTE helical scan tape drive manufactured by

EXABYTE Corporation, Boulder, Colorado. Each one hour video tape can store approximately 1.2 Gigabytes of data on one cassette tape. Data is extracted from the Exabyte tape drive via a translation program called CVTD (CASI Video Tape to Disk). The data can proceed along two different paths. Table 2 illustrates the CASI data flow.

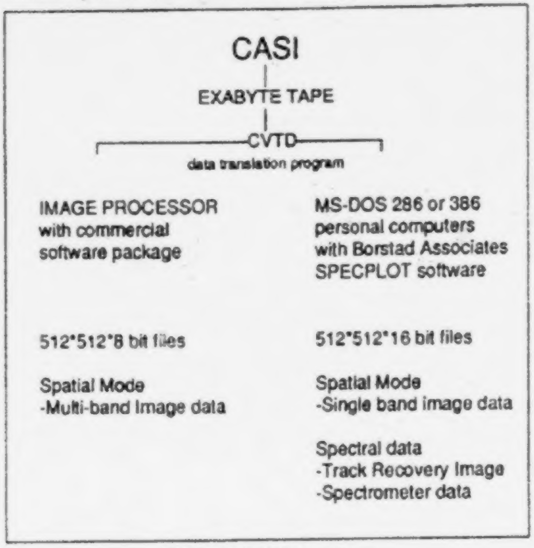


IMAGE PROCESSOR with commercial software package	MS-DOS 286 or 386 personal computers with Borstad Associates SPECPLOT software
512*512*8 bit files	512*512*16 bit files
Spatial Mode -Multi-band Image data	Spatial Mode -Single band image data
	Spectral data -Track Recovery Image -Spectrometer data

Table 2. CASI data flow.

Spatial data from the CASI is in 16 bit format and such has to be transformed to 8 bit format to allow the data to be displayed or analyzed on a image processing system. CVTD allows a user to define a bias or scalar when translating to 8 bits. CVTD writes out 512 pixel by 512 line image files. These files may be single band or band interleaved files. Presently CVTD translates spatial data into PCI EASI/PACE file format as this is the image processing system used by Borstad Associates. Once translated these files can be manipulated using any other the standard image processing techniques available to a user.

Spectral data from the CASI can be transferred to an image processing system but the translation from 16 to 8 bits can be a severe limitation when working with low radiance signals such as chlorophyll fluorescence. To analyze the 16 bit data from the CASI, Borstad Associates Ltd has developed a software package called SPECPLOT. SPECPLOT was designed so that analysis of spectral data could be done on a VGA equipped MS-DOS AT, 286 or 386 personal computer. This eliminates the need for an expensive image processing system and permits the translation and analysis of data to occur in the field.

SPECPLOT allows the user to display the track recovery image and one spectrometer track. The user can then extract single spectral or average groups of spectra from one or more spectrometer tracks. Mathematical functions allow the user to perform arithmetic between two SPECPLOT files or between a single SPECPLOT file and a constant. Plotting and graphing functions further aid in the analysis of the spectral data. SPECPLOT can also export or import ASCII number files for transfer of data between programs such as LOTUS 123. Hardcopy of the data can be obtained from a dot-matrix printer or laser printer.

Figure 2 is an example of data acquired by the CASI. This imagery was acquired April 18th, 1989, over and near the Canadian Forest Service research site at Shawnigan Lake, B.C. This site contains stands of second growth Douglas-fir (*Pseudotsuga menziesii* Mirb. (Franko)). The image data illustrated was acquired while operating in the multi-spectrometer mode. These track recovery images are monochromatic images with a spectral band width of 1.8 nm. and spatial resolution of approximately 2.5 by 3.1 meters. The schematic maps in Figure 2 show the location of one of 19 spectrometer tracks acquired simultaneously with the track recovery image. Thickened portions along the spectrometer track show the location for which spectral data was averaged. The spectral data was radiometrically calibrated and plotted using the SPECPLOT program (Figure 3).

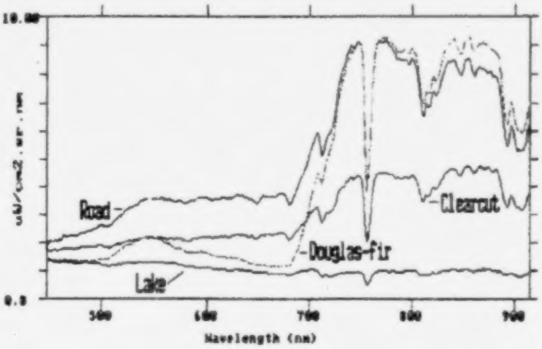
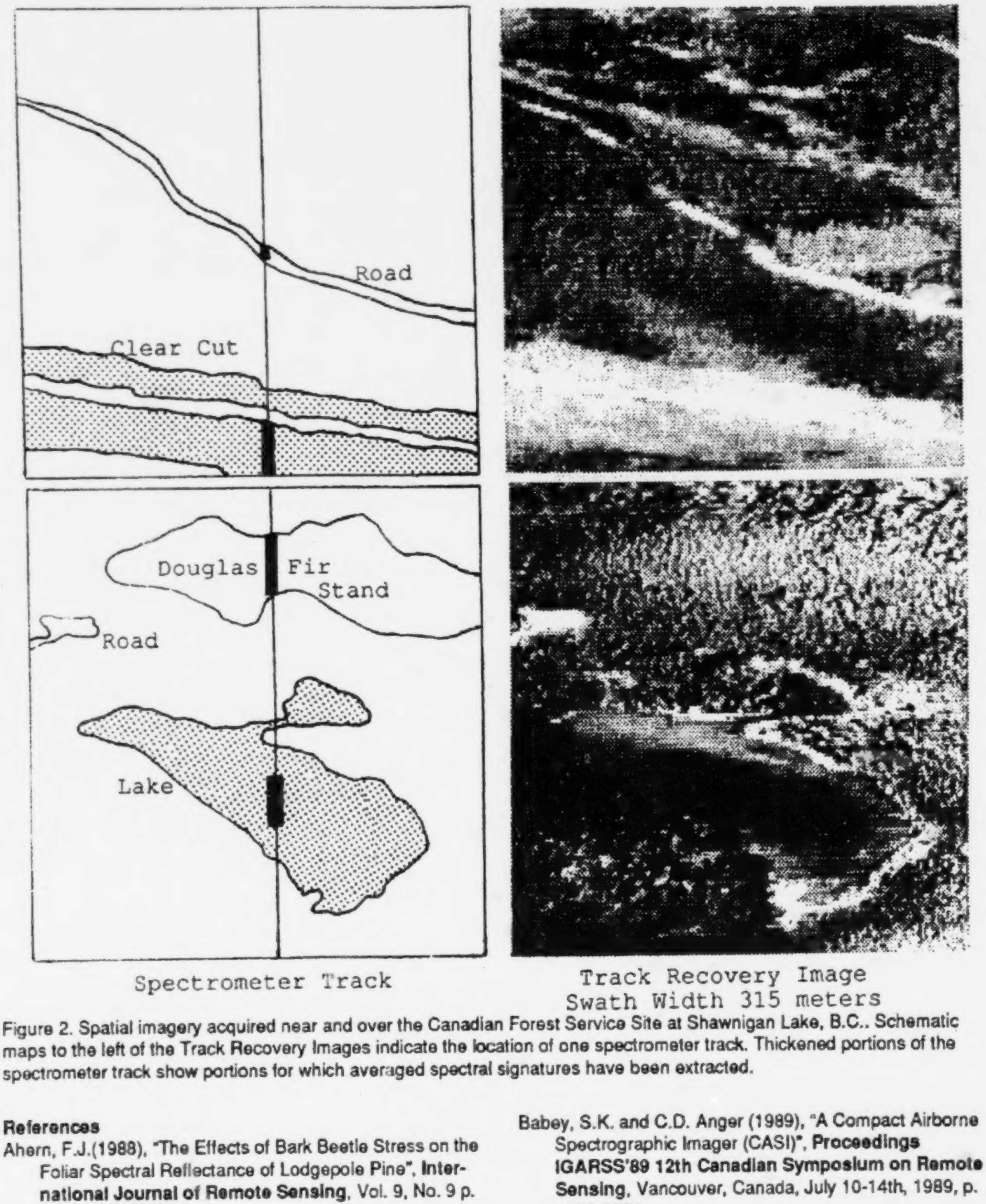


Figure 3. Average spectra for selected areas over Shawnigan Lake forestry research site. Spectra extracted from Spectrometer Track 19, CASI flight tape R048, File 14, April 18, 1989.

Conclusion

By examining spectral data collected over a forested area, a researcher is able to select or define spatial bands which best discriminate between several tree species, stressed versus non-stressed trees, etc. These bands can then be programmed into the CASI and the area flown in spatial mode. The CASI is ideally suited for algorithm development for larger aerial mapping instruments or for present or future spacecraft sensors. A researcher may incorporate the track recovery image and the spectral data into a GIS so that the effects of sun angle, topography, canopy density, etc., may be examined, a task that is difficult with present non-imaging spectrometers and other larger, and more costly equipment.

The CASI need not be restricted to airborne missions as its size makes it easy to transport and use in laboratory situations. A scenario where the CASI acquires spectral and spatial data over a target area in an aircraft and then is used to examined field samples in the laboratory later the same day is not unreasonable. The CASI is an exciting new remote sensing tool that can be applied to many applications in forestry and other fields.



Spectrometer Track

Track Recovery Image
Swath Width 315 meters

Figure 2. Spatial imagery acquired near and over the Canadian Forest Service Site at Shawnigan Lake, B.C.. Schematic maps to the left of the Track Recovery Images indicate the location of one spectrometer track. Thickened portions of the spectrometer track show portions for which averaged spectral signatures have been extracted.

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GIS'90 Symposium

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Digital Orthophotography - A New GIS Tool

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Abstract
Orthophotographs (accurate maps which look like photographs) have been used by various planning, engineering and mapping agencies for years. In raster digital form, they can now be displayed on computer screens; what is more, they can be perfectly registered to the corresponding vector maps used every day in a geographic information system (GIS). In the near future, many GIS projects (e.g., in utility companies) will use digital orthophotographs instead of planimetric vector outlines of buildings, roads, rivers, etc., for the landbase, showing parcel lines and utility networks in vector form, superimposed on the photographic image.

Introduction

Orthophotographs, accurate maps which look like photographs, have been used by various planning, engineering and mapping agencies for years. In raster digital form, they can now be displayed on computer screens; moreover, they can be perfectly registered to the corresponding vector maps used every day in a geographic information system (GIS). In the near future, many GIS projects (e.g., in utility companies) will use digital orthophotographs instead of planimetric vector outlines of buildings, roads, rivers, etc., for the landbase, showing parcel lines and utility networks in vector form, superimposed on the photographic image.

The Technology

An orthophoto can be transferred to digital format by passing it through a raster scanner, generating a series or array of pixels (dots). Each pixel is recorded in the computer by storing a grey-scale value in binary form (1 or 0). For example, an 8-bit byte contains 256 values (2 to the power of 8). This allows the storage of 256 graduations between total whiteness and total blackness, called the grey scale, so each pixel occupies one byte of storage. By combining many pixels of various values of grey, side by side, a picture is formed which can be displayed on a computer screen.

Good resolution of an image is difficult because a large number of pixels must be stored. A typical high-resolution monitor has about 80 lines per inch of resolution, so scanning an orthophoto mylar at 125 lines per inch, a typical resolution for many scanners, will allow a little 'zooming in' on the screen before the image becomes fuzzy. However, at 125 lines per inch, a 20" x 30" orthophoto sheet has 9,375,000 pixels; at one byte each, the file size is more than 9 megabytes, which is too large for most computers to handle in memory, particularly personal computers, and too large for any present system to handle several hundred or thousand orthophoto sheets.

Another factor is that scanning an existing orthophoto mylar adds additional cost to an orthophoto process. This is fine if you want to convert existing orthophotos to digital format, but expensive for new mapping.

Fortunately, technology is being developed to address the problems of storage and expense. Memory and storage problems will be mitigated by the computer manufacturers with cheaper, faster memory and optical disk drives. Image compression techniques will make the files smaller and faster to display. Lastly, the orthophoto maps themselves will be made by new digital image processing techniques which will be significantly improved from the optical/mechanical labor intensive methods which have been used for so long.

Perhaps the most exciting thought is that orthophotography will be available in color, as well as in black and white.

By the end of 1990, the capability to display digital orthophotos on several hardware/software platforms will be available. For instance, SUN, ARC/INFO, GEOVISION and Intergraph are currently developing orthophotographic capabilities into their systems. By the end of 1991, all the present systems, from AutoCAD to IBM's GFIS, should have the capability at an acceptable price.

The cost? Digital orthophotography will probably cost a little more than conventional orthophotography, particularly in the initial stages. As with most digital products, the cost will probably decrease with time. The versatility and suitability of the product, however, will undoubtedly place it in great demand.

The Product

What exactly is the product? How will it be used? How useful will it be?

Each orthophoto map file will probably cover an exact rectangle or square, parallel to the State Plane Coordinate System, if that is what the GIS uses. For a 1" to 100' utility basic map scale, each file may cover an area 2 000 feet N-S by 3 000 feet E-W, while for a GIS covering a National Forest at a 1" to 400' basic map scale, the coverage may be four or five square miles per file.

Depending upon the resolution of the computer screens used, a typical file will average between two and six megabytes in size. As it is best to keep the entire file in memory for quick searches (panning and zooming) and re-draw, RAM should be between four and sixteen megabytes for rapid movement within the file and to handle the operating system and the software (ARC/INFO, AutoCAD, etc.) resident on the system. The GIS will undoubtedly cover an area with multiple map sheets, maybe hundreds or thousands, or even (in the case of the big utility companies like the Public Service Company of Colorado, or Florida Power and Light, or timber companies such as the Fletcher Challenge Company of Vancouver), tens of thousands. Now the 'real' storage problems emerge. Ten thousand files of five megabytes each is fifty-thousand megabytes, or fifty gigabytes. No problem! At three gigabytes each, only 17 optical disks are needed to store all of the data, using WORM (write one read many) technology, which is available, although not perfected, today.

Once a raster orthophoto file is in the computer, this may take about thirty seconds, more for AutoCAD, less for a SUN workstation, it will immediately be in registration with the coordinate system, as each pixel will have its own coordinates. Thereafter, any vector GIS file, such as parcels and the associated text (parcel numbers, road names) will automatically be exactly registered, and the orthophoto will act as just another layer of the GIS. Provided that both the orthophoto map and the parcel map are accurately constructed, they should fit together perfectly.

It is important to realize that while vectors may contain topology, such as connectivity, networking or polygons, the raster image has none of these. It is a dumb, unintelligent layer; however, it has the excellent characteristic of being a picture, with all the visible details, such as sidewalks, driveways, buildings, trees and other features of a normal photograph.

There are other uses for digital orthophotography. Heads-up or screen digitizing will be possible through digitizing with the screen cursor on top of the raster image. It is very likely that utility companies will construct their utility networks this way. TIGRIS, for instance, the new Intergraph GIS software, allows the construction of networking topology at the time of digitizing; heads-up digitizing on top of an orthophoto landbase could be an ideal solution. IBM's GFIS software also lends itself to this application.

Obviously, there are some obstacles to overcome, but none is insurmountable or impossible. To reach a working, cost effective solution will require developments in techniques, hardware and software, not to mention librarianship!

Conclusion

Raster scanning and image processing have been made possible by advances in computer graphics technology. Within a short time, GIS will be taking advantage of raster technology by employing a brand new, but simple to use tool, Digital Orthophotography.

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Mapping the Land and Forest Types of Canada at Very Small Scales Using NOAA Imagery

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Abstract
Cloud-free composite National Oceanic and Atmospheric Administration (NOAA) imagery of one season for all of Canada can be geo-corrected and classified to land and forest types. Digital imagery of the appropriate resolution (1 km) can be used to generate very small scale maps (1:2 million and 1:7.5 million) with a high degree of automation.

Background

"The first notable description of Canadian forests on a national scale was W.E.D. Halliday's 'A Forest Classification for Canada' published in 1937." This is a quotation from J.S. Rowe, who, with others, updated Halliday's work in 1959 and revised it in 1972 as 'Forest Regions of Canada' (Rowe, 1972). These remarkable efforts mapped and described the country's major regional forest communities as Forest Regions and Sections. The work was so well done that even today, with our greatly improved knowledge, it provides a standard working reference. The AVHRR mapping described in this paper strongly endorses what a generation of forest resource specialists have come to know and respect as 'Rowe's Regions'. Canada's Forest Inventory is now being used to quantify these regions for the first time.

Rowe's regional descriptions of forest communities did not map forest types. In 1979, Forestry Canada, supported by Agriculture Canada and Energy, Mines and Resources (EMR) Canada, produced a 'Provisional Forest Map of Canada' at 1:5 million scale. This provisional map was seen as the first of two stages, and was the "rapid integration of existing forestry data scattered throughout many federal and provincial maps, survey reports, atlases, etc," to portray "the forest and non-forest areas without an elaborate classification." (Gimbarzevsky,1979). The second stage was proposed as a "classification of these forest areas into broad cover types using more recent forest inventories, aerial photography or Landsat imagery."

The Provisional Forest Map is still a standard for display, and has been used, for example, to provide the forest cover background of the map "Canada Pulp and Paper Mills", published as part of The National Atlas of Canada, 5th Edition (EMR Canada, 1985).

The maps mentioned above were produced without benefit of today's 1 km resolution images, digital image analysis, and computerised mapping.

Working at the local level, most of the forests of Canada have been covered in the last four decades with forest inventories which map and describe individual stands (or 'type islands') at about 1:20 thousand scale. Forestry Canada, with the cooperation of the provinces and territories through the Canadian Forest Inventory Committee (CFIC), has developed the Canadian Forest Resource Data System (CFRDS) as a national geographic information system (GIS). Vithin CFRDS, Canada's Forest Inventory (ForCan, 1988; Gray, 1989) and Biomass Inventory (Bonnor, 1985) have aggregated many stand level inventories to the map sheet level for entry into CFRDS. Each source map sheet became one in the 43 thousand data cells. These data bases can be used to present remarkable maps of the country's forest and its characteristics, but the maps lend themselves best to display at scales of about l:20 million or smaller.

It is interesting to note that CFRDS made early use of GIS technology, starting with the cellular maps of the 1981 national forest inventory. The development of CFRDS contributed to the diversion of Forestry Canada's resources from the second stage of the Forest Map of Canada. Some work did, in fact, begin on the collection of information from many sources, and completion was also scheduled for 1981.

EMR Canada and Forestry Canada continued to recognise the need for a better forest map, and saw it as a missing component of The National Atlas. When negotiations were reopened, it was decided that such a map should have working and publication scales of 1:2 and 1:7.5 million, respectively. The map should show the three major forest types, which are softwood/coniferous, mixedwood, and hardwood/broadleaved/'deciduous'. The map should also show other major land/vegetation cover types if possible, agriculture, tundra, etc. It should show biological boundaries rather than arbitrary cellular boundaries, it should be as current as possible, and it should be as uniform as possible in terms of scale, resolution and classification schemes. Such a product would complement all the maps mentioned earlier, except {or the Provisional Forest Map, which it would replace.

The Right Imagery

Most forest cover mapping and map updating in current Canadian practice uses aerial photography, supported in some cases by satellite scenes (Haddon, 1988). These images and maps all have far too much detail for the task at hand. Even Landsat coverage is too detailed, and would present a major workload if used to develop the national map.

The advanced Very High Resolution Radiometer (AVHRR) imagery of the U.S. National Oceanic and Atmospheric Administration (NOAA) was developed primarily for weather purposes, and did not initially show much promise for the forest inventory community. Typical resolution is of the order of 4 km for global area coverage (GAC), but can be obtained by special request at 1 km local area coverage resolution (LAC). Approximately six NOAA scenes cover the vegetated areas of Canada. Coverage is repeated every day. Like Landsat and other satellite imagery, AVHRR can be geographically corrected and can be classified for ground cover with varying degrees of automation. Unlike most of its competitors, the pixel density of AVHRR is appropriate to this national mapping project, so image procurement and data processing are no greater than necessary.

In the summer of 1987, the Manitoba Remote Sensing Centre (MRSC) began their operational global crop monitoring program which made extensive use of NOAA satellite data in Canada and abroad. The key cooperators in this operation were the Canada Centre for Remote Sensing (CCRS) and the Canadian Wheat Board (CVB). Several aspects of the technology immediately impressed the National Atlas and Forestry Canada authors of this paper. These features were:

- appropriate resolution,
- frequent national coverage,

- ability to correct the imagery geographically to a very close fit with National Atlas base maps,
- apparent ability of MRSC to use AVHRR for quite reliable classification of most of the cover classes initially proposed, and
- ability to develop cloud-free composite imagery within one growing season.

The Pilot Project

With the cooperation of National Atlas and CCRS staff, the Petawawa National Forestry Institute (PNFI) of Forestry Canada contracted with MRSC in 1988 to produce a Forest Map of Manitoba. The key ingredients of the project were to correct AVHRR imagery geographically, to classify Manitoba forests, to experiment with the appropriate level of image filtering (cleaning, or noise reduction), and to present the results for review as a colour plot on paper at a scale of 1:2 million.

Manitoba was chosen because of the availability of existing satellite imagery combined with local knowledge and expertise. Manitoba displays a wide range of conditions across a centrally located province of medium size.

The primary data source was multi-date NOAA satellite LAC (1 km resolution) imagery acquired during the summer of 1988. A classification scheme was selected that described the diversity of land cover across Manitoba at the chosen map scale. Particular attention was given to classification of the forest. Automated image analysis was conducted using both maximum likelihood and parallelepiped classification methods. Training sites for the classification process were selected with the aid of LANDSAT data, atlas maps, and forest inventory maps.

The land cover classes identified were:

1. Arctic Tundra	Dwarf shrubs, sedges and lichen heath, also Arctic stoney lichen heath.
2. Transitional Forest	From 10% to less than 50% of the area is in forest land. Scattered coniferous or broadleaved trees and broadleaved shrubs.
3. Hardwood Forest	Forest in which 75% to 100% of the canopy is broadleaved. May include patches of grassland, marsh or fen.
4. Softwood Forest	Forest in which 76% to 100% of the canopy is coniferous. May include patches of grassland, treed bog, marsh or fen.
5. Mixedwood Forest	Forest in which 26% to 75% of the canopy is coniferous. May include patches of grassland, bog, marsh or fen.
6. Agricultural Land	Lands which are broken and currently dedicated to the production of field crops. Because of the small map scale being produced and the low resolution of NOAA satellite data, this class may include small patches of trees, river corridors, towns, villages and other small cultural features.
7. Rangeland/Pasture	Lands supporting native vegetation, i.e., shrubs and other herbaceous cover, with less than 10% tree cover. Includes open upland and lowland meadows, as well as improved land dedicated to forage production.
8.Water Bodies	All permanent lakes, rivers and streams that are large enough to be depicted at the mapping scale.
9. Other Non-forested	Areas which do not fit elsewhere into the Lands classification scheme and contain less than 10% forest canopy. Includes exposed rock and barrens.
10. Cultural Features	Large cities and towns capable of being seen at the chosen map scale.

The product was reviewed and approved by the authors with the assistance of the Forest Management Division, (R.H. Lamont, Chief) of the Manitoba Forestry Branch. Some topics considered in the review go beyond the interests of a GIS audience, and will be dealt with in more detail elsewhere in a remote sensing forum, but some points are appropriate in this paper.

Cellular forest type maps from the national inventory were used to assist the classification.

Human interpretation, drawing on local knowledge and experience, improved the results by assisting or locally overriding the automated classification.

Other sources of information were used where class differentiation was confused due to spectral similarity or fine spatial mixing. The transition between forest and agricultural land gave problems which were overcome by cutting in a 'mask' of agricultural land, provided in digitised form by Environment Canada. The foresters on the review panel were prepared to accept the under-representation of trees in these situations because of the predominant value of the agricultural land.

The final classification products were in a raster format theme file, which was then filtered with a minimum area cluster filtering technique. This removed the speckle effect where the product was too detailed for the map presentation. In this case, using a review scale of 1:1 million, polygons of 4 pixels (4 square kilometres) and less were filtered out, with those small groups of pixels being absorbed into the larger and more homogeneous classes surrounding them. The filter size (i.e., minimum area displayed) can be changed to fit map scale and client preference.

What is probably of most interest to a GIS audience is the efficiency displayed in the production of a cloud-free composite data base, and in the geo-correction to fit the cartographic base. After completion of the image analysis, the technology offers an opportunity for very efficient transfer of the classified data file directly to the cartographic specialists. Intermediate products could be displayed readily on a screen or other media (e.g., Aplicon colour plotter).

The National Map

Since the successful completion of the Manitoba pilot project, there have been further developments.

The participants have recognised that a land cover map can be generated which includes forest types, and that this would be of more benefit than a forest map alone.

This exercise has helped stimulate a federal inter-agency attempt to identify and define broad land cover classes which would be recommended 'standards' for this and similar work.

CCRS are obtaining complete AVHRR coverage for most of the vegetated portions of Canada across a full growing season, and are contracting with MRSC to produce cloud-free composites.

EMR Canada have contracted MRSC to complete the project for the rest of Canada for inclusion in the National Atlas Information System, for both electronic and paper maps.

The classified data will also be made available to others, such as provincial resource mapping agencies, who may wish to use it in their own map series and geographic information systems.

Technical Advances

The present pace of technical change in geomatics is incredible, and it is interesting to re-read Gimbarzevsky's description of the "Stage Two" project which was begun a mere ten years ago. The project was suspended for organisational rather than technical reasons, but examination of the work which was done shows the limitations of the time. The plan was to compile a Forest Map of Canada "using more recent forest inventories, aerial photography or Landsat imagery". The labour and expense, the geographical distortions, the several vintages of source information, and the variations in classification and aggregation, were a necessary part of the exercise a decade ago.

Who could have forecast then that a weather satellite, with only six scenes covering Canada's enormous sweep of vegetation, could be used to map the forest and other vegetation types with such precision? Ten years ago one could hardly dream of today's computer power for classification and mapping. we wonder what marvels will be reported in ten years time to GIS 2000.

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Special Interest Group

Session G4
Integrated GIS for Municipal Applications

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GIS'90 Symposium

Vancouver, British Columbia
March 1990

Overview of GIS for Regional and Municipal Applications

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Abstract
The fields of municipal land use planning, engineering and property file tracking and management are some of the fastest growing application areas of GIS in North America. This presentation will provide a perspective on the many applications, importance and anticipated developments of GIS for municipal use.

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Case Study: Oxford County, Ontario

Liz Ottaway
Deputy Planning Commissioner
County of Oxford, Ontario

Abstract
This paper will describe the establishment and operation of the Oxford Land-Related Information System, which features shared access to a database of land-related information that has been integrated from a variety of government sources.

GIS'90 Symposium

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Land Information Management - The Provincial Strategy as it Relates to Local Government

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Abstract
The B.C. government has formed a Land Information Strategic Committee (LISC), consisting of senior managers involved in land information management. Subcommittees deal with resource-based GIS and parcel-based land information. A forum was thus available to deal with the discussions and negotiations necessary to develop a more unified view of land information on a comprehensive provincial scale.

A long range strategy has been completed and commenced and will extend over the next three to four years. This paper reviews the strategy, its implementation and the outcomes that are anticipated.

Introduction

Since colonial times, the British Columbia Government has been active in the fields of mapping and land information. Given the importance of resource-generated revenues to the Province, and the impossibility of managing these resources in even a primitive way without maps and ledgers, the early mapping and land information systems developed in response to specific needs and with a narrow focus.

These systems worked fairly well for over a hundred years. For example, the Crown Land Registry Information System, with which I am most familiar, is a complete graphic and textual record of all Land Act dispositions of Crown land. It has performed and continues to perform its original function very well. What we have come to recognize, first, is that a simple single purpose function is inadequate in the complicated world of the 1980's and, second, that there are opportunities, due to the advance of technology, to become more productive by changing our ways of doing business.

Through the 1980's, the realization spread through the various government ministries that there was a need for closer cooperation and better integration of the rapidly developing land information systems. Although many efforts were made by program directors to work more closely with their opposite numbers in other ministries and to produce information in common formats, this proved in practice to be quite difficult to achieve. It is very tempting to utilize scarce resources as efficiently as possible in your own program without paying sufficient attention to the longer term or the common good.

At the same time, there was growing concern among ministry executives, Treasury Board staff and Treasury Board itself as to whether there was too much duplication and redundancy in mapping programs.

Government Organization

As part of the major government reorganization of July, 1988, the Lands components of the Ministry of Forests and Lands were separated to form the new Ministry of Crown Lands. The Surveys and Resource Mapping Branch, formerly with Ministry of Environment, was transferred to the Ministry of Crown Lands and the Ministry was mandated as the lead agency for mapping and land information in government.

The Cabinet directive authorizing the lead role in land information for Crown Lands was very brief and one of the first tasks of the Ministry was to clarify the extent of its mandate and to develop a strategy for carrying it out.

The first step was to form a Land Information Strategic Committee (LISC), chaired by the Assistant Deputy Minister, Crown Lands, and consisting of senior managers from other ministries with major activities in land information management. In order to ensure representation from all the major players, subcommittees were formed, including one to deal with resource-based GIS and another to deal with parcel-based land information. A forum was thus made available to deal with the discussions and negotiations that would be necessary in order to develop a more unified view of land information on a comprehensive provincial scale.

Land Information Strategy

The next step was to develop a long range strategy and secure its acceptance by government. This process was completed in September of 1989. The third step is the implementation of the strategy, a process which will continue over a period of years with most organizational and developmental activities concentrated between 1990 and 1993. The primary objectives of the strategy are:

1. To simplify access to land information by all users,
2. To increase the exchange of information both within the provincial government and between the provincial government and local government and the private sector,
3. To increase efficiency and reduce redundancy,
4. To promote cost sharing among information managers and users,
5. To increase private sector involvement and enhance marketing opportunities,
6. To improve the resource planning and decision making process by providing better land information to resource managers.

The strategy identifies three levels of land information, in terms of the need for access by users. The first level is corporate information, being primarily cadastral, topographic and major administrative boundary information. This information was identified as critically important to most users and thus will be subjected to the most stringent requirements as to reliability and ease of access for users.

The second level of information is that which is program related but for which there is a significant need by users other than those involved in the specific program. Examples of this type of land information are forest inventory mapping and water licences. This information will have to be translatable and easily accessible to other users but responsibility for quality and currency will remain with the program managers.

The third level of land information is program related and of little or no general interest to outside users. Examples of this level of information might be silvicultural treatment records and real time air quality observations. The assignment of each type of data to its level in the hierarchy will occur as the strategy is implemented.

Ministry Responsibilities

The responsibilities of the Ministry of Crown Lands in implementation of the land information strategy are as follows:

- Creating a comprehensive directory of government land information,
- Publishing policies, specifications and procedures for managing land information.,
- Supporting the Office of Information Technology in approving land information developments,

- Establishing a single source for gaining access to virtually all government land information for both government agencies and the private sector,
- Continuing development of the digital topographic base mapping of the province (TRIM), and
- Continuing development of the cadastral (property ownership) information base.

The responsibilities of ministries other than the Ministry of Crown Lands which manage land information are twofold:
- Providing up-to-date standardized information for a central land information directory., and
- Managing their respective land information and systems according to prescribed policies and procedures.

The local governments or Crown corporations, if included within the land information infrastructure as it develops, would have responsibilities equivalent to those of ministries other than Crown Lands.

The Cadastral Database

Although there is variety of resource data which is of interest to local governments and which will be made more accessible to them by implementation of the land information strategy, there is no question that the cadastral (property ownership) database will be of the most value. For this reason, I will discuss the requirements for this database and database management system as I envision it, in some detail.

Current compilation, management and update methods include a large element of duplication of effort, primarily because of the numerous agencies working independently and to different scales and standards. As well, the cost of maintaining currency of data is very high. The design of the new Database Management System will address these problems.

In designing and using parcel-based GIS, it is important to remember that the UTM coordinates of parcel corners are nothing more than the best currently available estimate of their real world locations. The legal definition of the parcels on the ground is governed by survey posts or other local evidence, combined with original plans or records and is independent of the system coordinates. It is important that the system reflect this, by maintaining parcel integrity and parcel relationships when corner coordinates are changed. Relationships of points and lines which make up parcels must remain undisturbed in response to introduction of new coordinate values for corners. Similarly, the system must recognize that Parcel A is adjacent to Parcel B and must maintain this relationship if new coordinate values are introduced for one of these parcels.

Positional accuracy is important, however, in that it provides the linkage between the parcel databases and other databases, including topography and various infrastructure databases. For this reason, it is necessary to review user needs, as related to costs of data acquisition, and to design a system which is capable of accuracy improvement over time. The corner attributes of parcels in the database should include estimates of positional accuracy, which can be generated as data is loaded. This will provide a basis for future coordinate adjustment when new and more accurate data are loaded.

Several levels of positional accuracy will have to be accommodated. It is clear, for example, that the need of users for a positionally accurate cadastral database is greater in intensively developed urban areas than in a suburban or rural environment. In British Columbia, forty-five of our urban municipalities have been proclaimed or are in process of proclamation as integrated survey areas and contain sufficient control monumentation to make it quite practical to develop an accurate cadastral database. These municipalities contain about 690,000 parcels, or 57% of all the parcels in the province. In parts of the province outside of integrated survey areas, lesser standards will apply.

The Cadastral Database and Management System must accommodate the data which is required by most users while allowing those with more specialized needs to readily customize it to suit their requirements. For example, the most basic Land Act or Land Title Act parcels will probably be identified by their PIN or PID from the Crown Land or Land Title Systems. This data will then be manipulated by B. C. Assessment Authority to create assessment parcels, each of which will consist of one or more Crown Land or Land Title parcels.

Many users, including land surveyors, engineers and architects, will require more detailed information than that found in the basic Parcel Database. It will be necessary for the Parcel Database to reference another level of graphic information, the plan database, which will consist of digital models of the original survey plans, uncorrupted by any adjustment procedure. Hierarchical or parent/child relationships, as well as strata (condominium) and airspace or subsurface interests will also be identified by pointers from the Parcel Database.

The system must be independent of scale so that maps of any scale can be generated from the data. Users should be able to draw upon the database to generate map products of many degrees of sophistication, from simple line diagrams with tabulated labels to cartographically pleasing maps. The simplest graphic products would be generated from the database with little or no human intervention. Sophisticated map products or graphic displays, especially if overlaid against topographic or infrastructure graphics, will require editing to eliminate labelling and other conflicts.

The database must be generic in the sense that it will be accessible to a number of hardware platforms.

The Database and Database Management System must accommodate data from a variety of sources, including:
- Existing large scale digital maps,
- Existing hardcopy large scale maps,
- Existing medium scale digital maps, and
- Digital and hardcopy source documents.

It is obvious that data from each of these sources will require greater or lesser degrees of effort during the conversion process in order to bring it into compliance with the database standards.

It will be necessary to assign a unique identifier to each parcel and to identify topological relationships as the parcel data is converted. The Database Management System will have to incorporate a series of tests for topological integrity at the time data is accepted into the system.

Present plans call for development work on the Cadastral Database Management System to commence during 1990-91. Once the system is developed, all cadastral compilation funded by the Provincial Government will be carried out in accordance with the prescribed standards, which will also be made available to all other cadastral data management agencies, including municipal governments.

We expect to obtain input from a large number of cadastral data managers and users as part of the development process.

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Base Mapping in the Municipality of Surrey

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Abstract

The Municipality of Surrey's original base maps were drafted in the 1930s. In the 1960s additional information for sanitary sewers, drainage and the water distribution system were added on mylar overlays.

By the early 1980s it was obvious that the existing maps were not able to meet the needs of a growing community. An internal study identified some of the problems inherent in the existing manual mapping system.

As a result of this study the Municipal Council, in 1983, decided to proceed with the installation of a computer graphics system to automate the mapping operation.

The goals of the project were:

1) to enhance the capabilities of the mapping system to permit the production of customized maps at any scale with any content; 2) to convert all information to the metric system;
3) to improve the accuracy of the cadastral data knowing that there were errors of 10 metres or more in some areas and;
4) to improve the timeliness of map data.

In September 1985, the District of Surrey completed the conversion of the Municipality's cadastral base map inventory of 55 000 lots from mylar-based originals to a digital record.

Introduction

In September 1985, the District of Surrey completed the conversion of the Municipality's cadastral base map inventory of 55 000 lots from mylar-based originals to a digital record. This digital base was entered using coordinate geometry and the majority of lot corners are now within 3 to 4 cm of their actual position. The project had started in mid-1983 and required 11 man years of effort to complete.

Background

The Municipality of Surrey covers an area of 140 square miles and is located 45 minutes east of downtown Vancouver. It is strategically located between the Fraser River on the north and the International Boundary on the south.

Surrey's population has grown from 147 000 in 1981 to 215 000 today, with continued rapid growth expected well into the next century. As well, the character of the community has changed from rural to suburban and is now becoming urban in some areas.

All municipalities maintain maps for various purposes. The recording of the location of engineering works is a requirement of the Provincial Municipal Act. As well, accurate base maps are required for everything from planning new neighbourhoods to fire equipment routing. Surrey's original base maps were drafted in the 1930's. In the 1960's additional information for sanitary sewers, drainage and the water distribution system were added on mylar overlays.

However, by the early 1980's it was obvious that the existing maps were not able to meet the needs of a growing community. An internal study identified some of the problems inherent in the existing manual mapping system. One problem was the confusing mixture of imperial and metric dimensions created when the survey industry converted to the metric system in 1978. For example, where a new plan was added to an existing map, the common lines would be dimensioned twice, once in feet and once in metres. Other problems involved scale. Base maps at a scale of 1:2500 were created by using square mile sections with major roads forming the limits of each map. This convention was efficient for mapping but every time a map of a major intersection was required, four base maps had to be juggled to produce that map. Also, manually drafted maps could not be replotted at a different scale without considerable work. The study also noted that the originals were subject to physical deterioration and were not secure from fire or other hazards.

As a result of this study, the Municipal Council, in 1983, decided to proceed with the installation of a computer graphics system to automate the mapping operation. The goals of the project were:

1) to enhance the capabilities of the mapping system to permit the production of customized maps at any scale with any content,
2) to convert all information to the metric system,
3) to improve the accuracy of the cadastral data knowing that there were errors of 10 metres or more in some areas, and
4) to improve the timeliness of map data.

The Creation of a Digital Base

Surrey considered two main options for input of base map data.

The first option was to digitize or trace the existing maps. Knowing that there were significant errors on the existing maps and that an error which is acceptable at a scale of 1:2500 is not acceptable at 1:500 or 1:200, this was not considered the best method of input.

The second option was to use coordinate geometry and spend more time initially to create a reliable and accurate foundation for all geographic information.

To use coordinate geometry, an accurate set of control points must be available. Surrey was fortunate in this because it had been declared an 'Intergrated Survey Area' in 1968. An integrated survey area is created by establishing survey control monuments at key locations, each visible to two other monuments. All surveys in an integrated survey area must then be related by distance and direction to at least two of these control monuments. In Surrey there are 1300 such monuments and because much of the development in the Municipality occurred after 1968, the majority of the lot corners in Surrey are related to the control network.

In the creation of the digital base, the sequence of input was from the most accurate to the least accurate information. The first portion of the lot data set entered was the survey plans which had been related to the network of control monuments provided by the Provincial government. This set of integrated plans was entered using coordinate geometry with the errors adjusted to fit to the monuments and other integrated surveys.

The second portion of the data set came from field ties done by Municipal crews to locate key points, generally section or quarter-section corners, in areas which did not have integrated survey plans. This work took approximately 6 months with one-half of the work done in preparation for the project and one-half of the work being done as the project progressed to confirm the location of lot corners.

The third portion of the data set was those plans which were between the integrated plans and field-tied corners. They were also entered using coordinate geometry and all errors were proportioned using accepted land survey practice and principles of evidence. For example, all roads were given their full width unless there was evidence to the contrary and explanatory plans were given their full area where possible.

The last source of information used were orthophotographs of the Municipality. These were used to locate natural boundaries such as shorelines and rivers as well as minor watercourses.

In addition to the graphic information, attribute records were attached to each element. For example, a lot has an owner type (private, park, school, etc.) and an area; a survey monument has x-, y-, and z- coordinates and a road centreline has a length.

Surrey now has a base which is reliable and accurate. One base map is available for all applications regardless of scale and provides flexible plotting and reporting options. As well, geographical data can be located by specifying unique attribute data such as a plan number, an address or a road intersection.

Beyond the Base Map

The completion of the base is just the beginning. It is the foundation on which to build many more 'stories' of data.

Information which is now on the mapping system includes 66 500 addresses and 820 km of sanitary sewer mains and 41 000 connections. In addition, the conversion of the water distribution system is 75% complete and some planning data such as zoning, Official Community Plan designations and concept plans are being automated.

The Future

Surrey's implementation of a GIS is now in the 'pilot project' phase. The availability of a solid, reliable digital base allows a significant area to be used in the pilot project. In the mapping project, the work of level content and definition had been done. This work was a good starting point for the design of the GIS data model. Also, with the majority of the high priority data sets either completed or almost completed, GIS can be functional as soon as the pilot is complete without any additional data input.

Conclusion

An estimated 80% of all data required and managed by a local government is geographically related. Effective management of this data so that it is available to the appropriate people, in the correct format and in a timely fashion requires sophisticated tools beyond those of a draftsman and a sheet of mylar. confirm the location of lot corners. The transition from a manual to an automated mapping system is time-consuming, costly and fraught with difficulties. In Surrey's case, the key to success was Planning. By observing the following guidelines, Surrey paved the way for a successful system implementation:

- plan early and in detail,
- plan for today and keep as many future options as possible. Coordinate geometry would still be our method of input if we started again,
- involve people from all levels of the organization. An excellent relationship between those responsible for data input and the programmers was a tremendous help,
- establish achievable goals,
- move slowly; build as you go; experiment; find the best paths to follow,
- over-manage at the start, and
- plan user friendly systems as tools for people.

This system was developed as a tool to organize the mountainous volume of data required by the Municipality for effective decision-making. Its implementation has provided a solid platform on which to build future systems that will actually participate directly in the decision-making process. As the system evolves, electronic media will gradually replace the dependence on paper as a means for sharing and exchanging information. data.

The Future

Surrey's implementation of a GIS is now in the 'pilot project' phase. The availability of a solid, reliable digital base allows a significant area to be used in the pilot project. In the mapping project the work of level content and definition had been done. This work was a good starting point for the design of the GIS

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Case Study: City of North Vancouver GIS

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Abstract
This presentation will describe the implementation, current use and future plans for GIS in the municipality.

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Mapping California's Urban Forests

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Abstract
Over the past five years, Golden Coast Environmental Services, Inc. (GCES) has inventoried over 500 000 trees. GCES is an urban forestry information management firm specializing in street and park tree inventories for municipalities. Recently, GCES has seen a greater number of municipalities integrating this data with Geographic Information Systems (GIS).

Infrastructure elements have been a key concern in most systems; however, trees are often excluded. With a diversified staff of urban foresters and information systems specialists, GCES has shown the benefits of including tree data as a layer of information in GIS projects. Analyzing tree data against damage to sidewalks, presence of utilities and signs has been a great aid in municipal management.

GCES has used its urban forestry staff to develop a database of trees for over 30 communities throughout the State of California, four of which have been integrated with a GIS. The data has been collected for use in three different systems (ARC/INFO, INFORMAP III, and MAPINFO) for geographical information management.

This paper covers the following project elements: requirements analysis, GIS environment, database design, data collection, GIS integration and implementation. Benefits and drawbacks of the different projects will be discussed.

Background

A well managed tree population is a valuable community asset. Special attention is required to sustain a forest in today's urban environment. At the same time, increasing costs for public safety and welfare relative to tree care heightens the need for tree managers to become informed.

Golden Coast Environmental Services, Inc. (GCES) has linked managers responsible for tree care to the power of modern data management insuring proper care for urban trees. GCES has worked with numerous agencies in developing effective tree inventory and management systems. The detailed inventory produces the data necessary to obtain a precise evaluation of existing conditions. Combined with a well designed tree record keeping system, the inventory provides the means for automated tree management.

The automated system was designed to help today's urban forester accurately evaluate present needs, anticipate future projects, document schedules and performance to maintain public health and safety, and properly budget available funds. The GCES automated management system meets the challenge of modern tree resource management. Four such projects have been integrated with a GIS. The cities of Irvine, Rancho Cucamonga, Santa Ana & Santa Barbara, California have GIS projects of different sizes, but have all incorporated tree inventory data.

Requirements Analysis

The requirements for an urban tree inventory differ from natural forest inventories, the major factor being the environment. Urban trees have been taken from their natural environment and subjected to harsh punishment. Concrete, cars and utility lines all prohibit natural tree growth in urban areas. To collect data which is useful for urban tree management, advance planning is required.

With five years of experience inventorying urban forests, the requirements are now becoming standardized. However, the process is still used to clarify the exact needs of each project. There are five main categories of data collected:

location,
species identification,
physical characteristics,
maintenance classification, and
environmental conditions.

Each of the cities in the four sample projects used the experience of a consultant to develop the requirements for their tree inventory. Since a standard has been developing by GCES, this phase of the project was very simple yet critical. Beginning a project without the assistance of experienced professionals is the greatest cause of failure. Most municipalities who have attempted a tree inventory without assistance don't have a program which works.

A requirements document should be written during this phase of the project. It will serve as a great tool in requesting proposals for work. The documentation can also be used for assessing progress and the completion of goals. Without proper documentation, your goals will unknowingly change and lead to your dissatisfaction with the final product.

GIS Environment

The hardware required to operate a GIS often exists before selecting the software. In three of the four sample projects, the hardware and software were selected before the tree inventory began. In the other project, there was no GIS in place and a PC-based program was implemented with the tree inventory as the initial layer of data.

The cost of workstations cannot be ignored when discussing GIS projects. A workstation can cost anywhere from $7000 and up. The three projects which were running their GIS on a minicomputer were limited to between 1 and 10 workstations throughout the city, due to cost. This required Management Information Services (MIS) staff to be in charge of processing needs for departments.

Relying on MIS for all GIS needs has caused a slower turnaround time for maps and other requests. However, in some cases, departments were relieved by not having to learn how to use the GIS. The PC-based GIS was used by the urban forester, not MIS. This required very user friendly software. The PC-based program was able to offer this.

Infrastructure data was the primary selling point for incorporating tree inventory data in the GIS. The three systems which were in place at the time of the inventory had underground utilities, water lines, electrical lines, streets, sidewalks, assessors data and parcel lines digitized. Trees were the first animate layer of data included in the system.

Table 1. Tree Inventory Data Fields

Location	Species ID	Physical	Environmental
Address	Botanical Name	Diameter	Growspace Size
Street	Common Name	Height	Utility Presence
Tree #		Canopy Spread	Hardscape Damage
GIS #		Vigor	
		Condition	

In each of the projects, the inventory data was to be used by a separate application. This would be for daily retrieval and updating. In two cases, the inventory data was distributed on another computer. In these cases, the GIS updates a copy of the data on a periodic basis, as needed.

Database Design

The design of the database in each of the projects has been determined by an existing and separate application. TreeKeeper, GCES's tree management software, is used to update the tree inventory while tracking work histories and citizen-generated work orders. In three of the four projects, the data is stored on a PC in a dBASE file format. In the other project, the data is on the GIS host in an ORACLE format.

The primary use of the tree data was for TreeKeeper. This required a special interface to the GIS. This has been done through a key field in the tree database. The field has been named gis# and stores a unique number for each record. This same number is stored in the GIS datafile for trees. This key field is used for updating information from TreeKeeper to the GIS. This approach has been used in two of the four projects.

Data redundancy is an issue which MIS managers love to resolve. The above example gives them an opportunity for that in the future. In the other two projects, an individual database has been used and shared by both systems. One project has a minicomputer as the host and the other has a PC. Sharing the same datafile between the two applications can only happen if the GIS and the tree management program store and read data in the same format.

Address matching and physically digitizing trees are two options for uploading tree data to the GIS. In the PC-based GIS, trees were geo-coded; this function matches and assigns records by address. This is not a process to be used by someone who requires an exact physical location of the trees on maps. However, it is much less time consuming than digitizing.

There are many reasons why exact physical locations are not necessary for trees. Trees have root systems which cannot be predicted or surveyed. The location of a tree trunk above ground does not preclude it from being suspected of causing damage to a sidewalk 40 feet away. A tree whose location is digitized to an accuracy of 1 inch would not be of benefit even a tree expert in determining whether tree roots are the cause of the damage. The tree's crown can be as devious as its roots. This is something that is too dynamic to update in a GIS. Pruning can reduce the crown spread by 50% and new growth will increase it within months.

However, above ground interference with utility lines and landscape design are important reasons to have the trees digitized as opposed to address matched. Through our experience, we have found that the tree data is not going to be used for precision work. Maps for tree care contracts are the greatest use of GIS in urban forestry. The contracts list the addresses of trees from the inventory and don't require precise plotting.

Data Collection

Tree inventories are traditionally taken by horticulturists walking the streets and entering data into hand-held computers. Addresses and street names are collected for identifying the location of the trees. A tree number is also given to trees because multiple trees can exist at an address. This is the extent of location data necessary for address matching with the GIS.

In systems which will digitize the exact location of the tree, base maps are used for plotting trees in the field. A dot is placed on the map in the location of the tree. A sequential number is given to that record of information. Each number does not need to be recorded on the map since they are sequential. However, when corners, are turned the current number should be recorded to note the change of direction. If there are long blocks of trees, every 20th number should be recorded. The trees are later digitized as a layer of information in the GIS. When tree plantings are linear, inventories are taken up one side of the street then down the other. In urban forest inventories, 90% of the trees are planted this way. The other 10% are planted in open areas like parks. In open areas, inventories are more difficult.

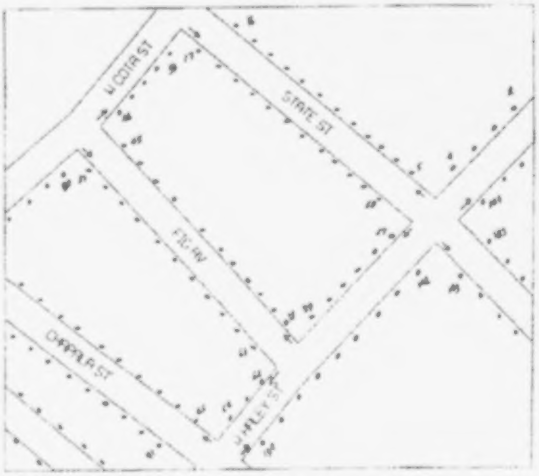

Figure 1. Typical Urban Tree Inventory Map

A divide-and-conquer strategy is implemented in open space tree inventories. Base maps are used to divide the area into smaller units using either physical reference points as dividers or setting up a grid based on measurements. Once units are created, each one is inventoried based on the data collector's own direction.

The tree inventories which include GIS numbering have slowed down data collection. In addition to increasing field inventory time, digitizing extends the timeline for integrating the data.

GIS Integration

In the projects which plotted trees, the first step of integration was digitizing. Only one field of each record was added during digitizing. The GIS number was input to link the tree inventory database. An algorithm should be used to increment and assign sequential numbers to each tree as it is digitized.

In two cases, duplicate databases are maintained on different systems in different formats. The data is needed and used on a daily basis for tree management on a PC; the data is needed and used less frequently with the GIS on another computer.

In distributed situations, to access the tree inventory data, an ASCII export-import routine is written. The tree management application exports the data to ASCII format. The GIS then imports the most current database into its own format. This results in two copies of the same data. The import routine searches on the key field and copies each record of data.

In the other two cases, the same database is shared by both applications. In one case, the GIS use of the data did not require a level of accuracy any greater than by address. Integrating the tree inventory was a one-step process. Each record was assigned an X- and Y- coordinate by address. In the other case, each record was assigned an X- and Y-coordinate by matching the GIS number with the point which was digitized. This was a two-step process: digitizing and coordinate assigning.

Since address and street are standard fields of data collection in tree inventories, address matching can happen at anytime in the future without any advance planning. The integration is also easier when the datafile is shared by the GIS and the tree management program.

Implementation

The step of digitizing the trees from base maps was the largest obstacle in implementation. The amount of work was overwhelming to the responsible parties. The MIS department was not usually interested in allocating staff for the project. The tree department did not have the staff which they could afford to assign to the project. Since the tree department had the greatest need for the data, they ended up digitizing.

The greatest use of tree data within the GIS has been in contracting. An urban forest manager can now easily plot all the tree locations which require maintenance. The ease in changing geographical parameters allows the manager to quickly redraw boundaries to determine the balance between work needed and funds available.

Analyzing damage to hardscape caused by trees can pinpoint species to target for removal. Displaying each species in a different color makes an effective presentation. In areas where spraying is needed for pest control, a GIS can quickly display areas which are most densely populated with the target species.

The urban tree inventory is an important management tool. The use of GIS will increase its effectiveness. In prior years, the often-neglected tree budget has excluded costly GIS. With the decreasing costs of technology and the increased awareness of information sharing, municipal management will be planting more trees in their GIS.

Conclusion

After integrating four tree inventory projects with geographic information systems, some conclusions have been made on methods used to complete these projects.

1. A GIS is not intended for day-to-day tree management.
2. A GIS is a great tool for geographic data analysis.
3. Plotting trees on base maps and digitizing the locations is not necessary for most GIS uses of tree data.
4. Address matching is the most cost effective means of integrating tree data with a GIS.
5. Tree inventory data is capable of integration with GIS at any time.
6. Integrating tree data and a GIS is preferred by sharing files with the tree management program.

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Issues in Acquiring GIS Hardware and Software

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Abstract
Municipalities considering the acquisition of a Geographic Information System (GIS) are faced with many complex issues. Making an optimum choice depends on a sound understanding of the hardware and software alternatives available, as well as an appreciation of technological trends. This paper describes and explains what these trends are and how they affect the implementation of GIS.

Introduction

GIS is defined as a system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems[1]. Other related systems which deal with spatial data are automated mapping and facilities management (AM/FM) and computer-aided design (CAD) for engineering applications.

Although software products exist which address these needs separately, the trend is toward GIS which incorporate all the required functionality in one package. Generally, the choice of appropriate hardware follows the selection of software.

Users should be aware, however, that many GIS have evolved from either a CAD or an analysis perspective and may be optimized for particular functions. Understanding your needs and the capabilities of these systems is crucial.

Other issues which influence system selection are the organization's structure, plans for growth, the need to interface with existing business data, and system cost.

Hardware and Software Trends

In order to make an informed system selection, one should be aware of the major hardware trends and software technology. Some of these trends are the move to workstations, RISC processors, relational databases, UNIX operating systems, windows, distributed databases, distributed processing, and local area networks.

Early geographic information systems were minicomputer and mainframe based since only these systems could provide the required computational power and data storage capacity. Access to the system was provided through expensive graphics terminals.

Unfortunately, the intensive computational and data transfer characteristics of GIS tended to negatively impact the performance of other host-based applications. Vendors realized the need to off-load spatial processing.

Vendors also realized that being tied to a particular proprietary architecture limited their market for GIS. Greater acceptance of GIS depended on finding lower cost generic system platforms. The answer appears to be powerful workstations and, to a lesser extent, microcomputers. Figure 1 shows the growth trend of the various GIS platforms.

Determining which platform is appropriate for your use requires an understanding of their technical and functional differences.

Although workstations are inherently able to handle 2D and 3D graphics, the microcomputer requires considerable upgrading. Most GIS vendors recommend a '386' chip plus additional memory in the order of 5Mb, a fixed disk with a capacity of approximately 100Mb, a math co-processor, a graphics video card, and a high resolution color monitor. A Macintosh II microcomputer can also be expanded in a similar fashion.

If the microcomputer is part of a network, then a LAN card and software are also required. You can expect to pay approximately $25,000 for such a configuration. This price overlaps that of many low-end workstations.

In comparison to the expanded microcomputer, a representative low-end workstation would include a 19 inch monitor with higher resolution graphics, a 150Mb fixed disk, 6Mb of memory, and hardware and software necessary for a network interface.

An increasing number of workstations come equipped with the Reduced Instruction Set Computer (RISC) chip. This technology is based on a simplified instruction set that provides increased performance at a lower cost. The power of workstation processors is in the range of four to 25 MIPS (million instructions per second) compared to three to five MIPS for our sample microcomputers. Table 1 compares the technical features of the microcomputer and workstation.

Table 1. Technical Feature Comparison

Feature	Microcomputer	Workstation
Microprocessor	Intel 80286, 80386	Proprietary Risc
Power	3-5 MIPS	4-25 MIPS
Memory	2-5 Mb	6+ Mb
Graphics Resolution	640 x 480 to 1024 x 768	1184 x 884
Operating System	MD-DOS, OS/2	UNIX
Cost	20-25 K	25 K +

Microcomputers are still appropriate for GIS where workstation features are not required and particularly for stand-alone operation situations.

We can expect the distinctions between microcomputers and workstations to blur as microcomputers extend their power upward and workstations provide greater functionality at lower prices. Evidence of this is the increasing usage of UNIX on microcomputers.

The majority of workstations use the UNIX operating system. UNIX is part of the 'open system' strategy which allows users to mix and match applications programs from various vendors. Theoretically, it should be possible to run an application program written for UNIX on any vendor platform that supports the UNIX operating system. Users are no longer locked into purchasing software for a particular proprietary system.

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[1] GIS World, Inc., The GIS Sourcebook, Ft. Collins, Colorado, p. 164.

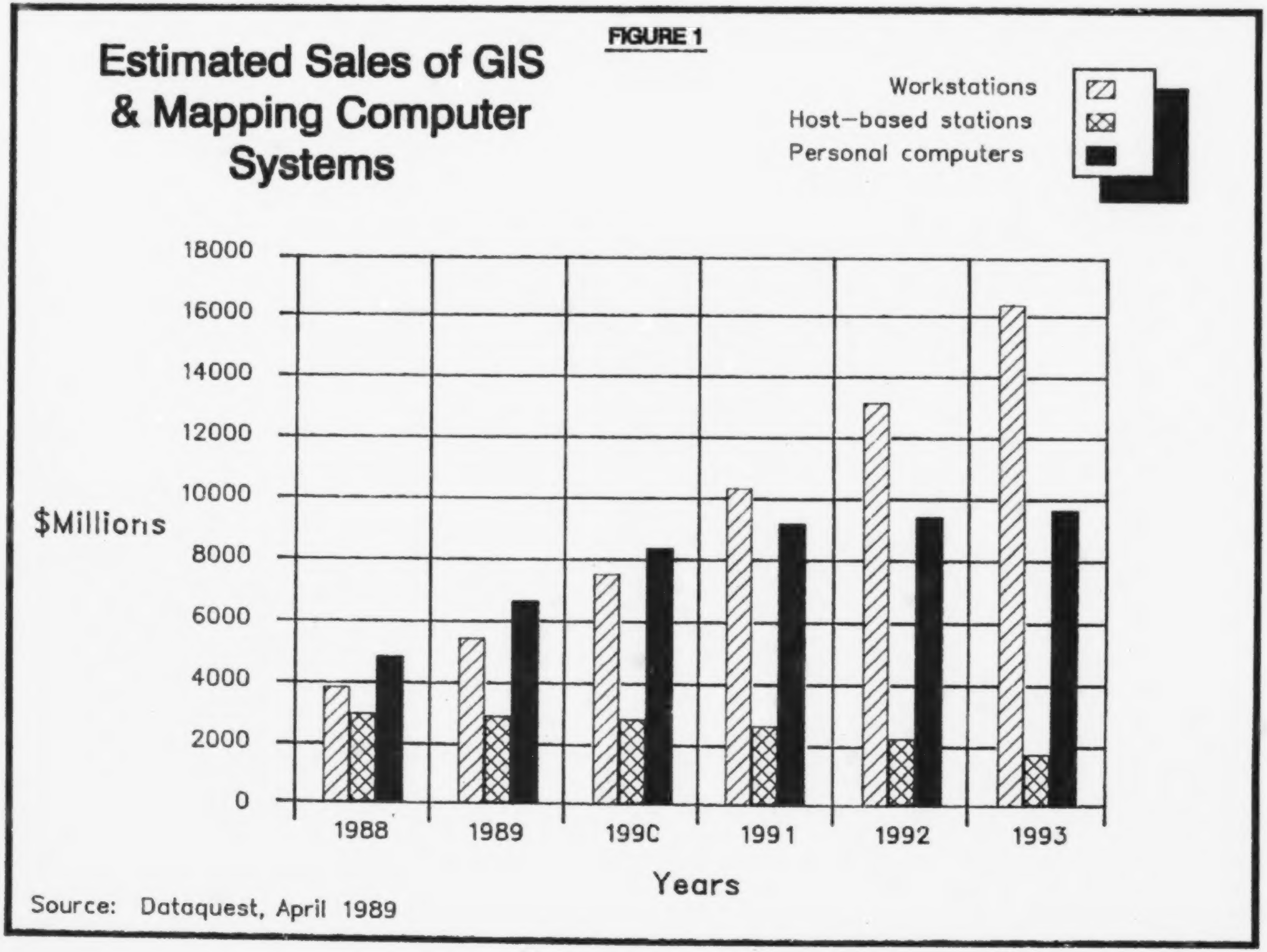

FIGURE 1

Estimated Sales of GIS & Mapping Computer Systems

Source: Dataquest, April 1989

The advantages of UNIX over the MS-DOS operating system are support for virtual memory, multi-tasking, multi-user, and file management and protection. Table 2 compares the functional features of microcomputers with workstations.

Table 2. Functional Feature Comparison

Feature	Microcomputer	Workstation
Virtual Memory	No	Yes
Multi-tasking	No (OS/2 Yes)	Yes
Multi-user	No	Yes
File Management Protection	No	Yes

Virtual memory allows the system to run programs too large to fit into memory. Portions of programs not in use are temporarily swapped to disk. This is a valuable feature since GIS programs tend to be large. MS-DOS and OS/2 operating systems do not provide this facility.

Multi-tasking is the ability to run more than one program or operation at the same time. This feature permits a database query or a time-consuming batch function, such as a plot to be done at the same time as graphic data are being displayed. The user interface to multiple tasks is often handled by a windowing program, which provides a consistent user view of each task. This improves productivity and requires less training to learn how to use applications.

MS-DOS does not support multi-tasking. Windowing on microcomputers gives the illusion of several ongoing tasks, yet, in fact, processing is suspended on all but the current window. OS/2 will give microcomputers true multi-tasking capability.

The multi-user feature allows more than one user or operator to utilize the processing resources of a particular workstation at the same time. This permits a query to be passed to a remote workstation that has the required data layers in its disk storage. The query will be handled simultaneously with other user processing.

Distributed Databases and Processing

The goal is to provide all users access to data anywhere in the network without the user requiring the knowledge of where the data physically resides. The implication of a distributed database means that the system can be configured to conform to the organization and allows the delegation of responsibilities for data. For example, the Planning Department would maintain zoning and community plan layers on their workstations, while Engineering would maintain infrastructure layers, and Finance would maintain property and assessment layers. These departments will be responsible for maintaining their respective map layers, yet they are available throughout the network to other users.

The use of workstations not only supports distributed databases, but also distributed processing. This allows additional processing capacity to be added incrementally to accommodate more users without degradation in the performance of the system. The functionality of GIS can be distributed among users according to their needs. For example, some workstations can run programs for data editing, others may have CAD, and still others programs for data analysis.

Since workstations allow distributed processing and distributed databases, file management and protection becomes a more complex problem. Responsibility for maintaining and managing portions of the database must be clearly understood. The UNIX operating system provides the system manager with the ability to set controls on who can access, add, or update data.

Although both microcomputers and workstations are capable of communicating over a local area network to access files, there is a significant difference in the way in which this is accomplished. In a network of microcomputers, data are located on a central server machine, and data stored on other microcomputers are not available to users on the network. Workstations have the advantage of peer-to-peer communications. Peer-to-peer communications allows any workstation to communicate directly with any other workstation in the network. This features supports the distribution of data to multiple locations.

Distributed Geographic Information Systems require communications networking software to link together systems which host the attribute data, workstations, and peripherals such as plotters, scanners, and digitizers. Standards for this software have emerged and are being used by most GIS vendors. Examples of these standards are TCP/IP and NFS.

TCP/IP is the foundation communications protocol upon which NFS and other network tools are built. NFS supports transparent access to files on other disks located throughout the network. With these communications tools in place, data and processing can be distributed across the network even if users are utilizing different kinds of hardware.

The benefits of these workstation features are improved productivity and greater data integrity, particularly in networked environments.

Interfacing GIS to Business Data

The shift toward workstations and microcomputers has achieved the goals of lower cost and wider market appeal for GIS. At the same time, it has introduced greater complexity in interfacing these GIS with host-based business data. The situation is complicated by the fact that most workstations use UNIX, whereas most municipal business applications run on other proprietary operating systems.

Many users see the capability of interfacing spatial data with existing business data as a major benefit thus justifying the use of GIS. This capability facilitates such operations as retrieving name and address data from a property file in order to generate notices to property owners within so many meters of a planning project, or displaying the location of dangerous goods and sprinklers for a commercial building.

Data in the business systems are often organized in sequential and indexed sequential files or in hierarchical databases, whereas the vendors have chosen to link to relational databases. Relational databases offer tremendous flexibility in managing data. New data tables can be added and relationships can be defined on the fly at the applications level instead of at the database system level. Thus, it is not surprising that virtually all GIS vendors have developed interfaces to link spatial data with attribute data stored in relational databases.

Users have the choice of either developing custom interfaces to existing files and databases or converting their data to a relational database. Neither of these options are trivial or inexpensive tasks.

If your business database resides in a relational database, your interfacing job is made easier. Many GIS vendors have developed the required interfaces or, alternatively, they can provide toolkits with which interfaces can be developed.

In summary, the acquisition of a Geographic Information System requires an appreciation of technological trends. These trends definitely affect the way in which the GIS can be used. Intelligent choices will facilitate greater data access and integration with the organizations' business systems.

Special Interest Group

Session G5
Artificial Intelligence

A Neural Net Model for Forest Management

Artificial Intelligence and GIS: Tools to Implement Adaptive Resource Management

Natural Language Interface to Geographic Databases

Automated Labelling System for the Alberta Vegetation Inventory Project

GIS'90 Symposium

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A Neural Net Model for Forest Management

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Abstract
The establishment of a 'smart' computer package for effective data processing and forest resource analysis will facilitate sound decision making concerning the multiple use of forest lands. Neural net technology has been studied for many years in order to achieve human-like performance in fields where problems were unlikely to be solved efficiently using traditional methods. A computer software simulation of such a net was developed and an empirical analysis was undertaken for the Peace River Timber Supply Area (TSA) in British Columbia to demonstrate the capability of the model for forest land management.

Introduction

Today, public forests are managed to provide society with various goods and services such as timber, forage, wildlife habitats, recreation and other environmental and ecological functions. The concept of multiple forest land use is now accepted as a sound and viable forest management policy (BCMOF, 1984). Multiple forest land use needs to allocate forest lands to meet several demands, aspirations, and desires of society with the constraints of certain biophysical and socio-economic conditions. The establishment of a computer package for effective data processing and forest resource analysis will facilitate sound decision making concerning the multiple use of forest lands.

Neural net technology has been studied for many years in order to achieve human-like performance in fields where problems were unlikely to be solved efficiently using traditional methods. A neural net is composed of many nonlinear computational elements (neuron) operating in a parallel manner. These neurons are connected with weights that are adjustable during the learning process which takes place to improve the performance. This technology, with a large processing capacity, can perform various tasks for information classification and pattern identification. Here, information involving uncertainties and fuzziness is accepted and approximate results will be output if they satisfy the manager's requirements. If the results are not satisfactory, the net needs to be retrained (Lippmann, 1987). Neural net modeling or forecasting operates in a parallel fashion in contrast to an expert system which adopts a sequential approach (Klimasauskas, 1989).

The purpose of this paper is to apply neural network technology as a decision support for forest resource planning in an attempt to bring it to the attention of resource analysts and planners. A computer software simulation of such a net was developed to test the capability in multiple forest land use management. Specifically, an empirical analysis was undertaken in the Peace River Timber Supply Area (TSA) of British Columbia to demonstrate the capability of the model for forest land management.

Background

Given the finite land resource base of British Columbia, there are uncertainties regarding the ability of the land to meet expected demands for forestry, agriculture, wildlife, recreation, and many other uses. One pressing problem in land use planning is to resolve whether a tract of land should be allocated for wilderness preservation or used for timber production. Society's choice of the use of land resources reflects a complex set of interrelations involving biophysical, social, and economic factors on both the demand and supply sides of the land use equation. Among these are the quantity, quality, land location, current land use, economic rent of the land, technology and management skill, and other social and political factors such as government policy and public perceptions toward wilderness preservation. How to allocate land resources effectively among multiple uses to meet various demands remains a critical issue (BCMOLP&H and BCMOF, 1981). Operation of land use planning will be facilitated by systematic analysis. It is obvious that more promising and effective analytical tools are desirable for resource analysis. Advances in computer technology have increased the design and use of computer-based decision support systems in land resource planning (Fabos, 1985; Buongiorno and Gilless, 1987). The development of computer software which is an essential part of the new analytical tool, can significantly improve current land use planning practices. These practices aim at selecting a desirable land use from a range of feasible options on the basis of a set of relevant evaluation criteria.

The General Framework of Neural Net Model

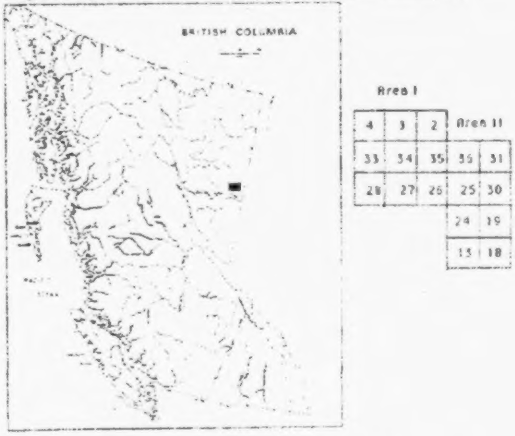
The basic structure of a general Neural Net Model (NNM) is described in detail by Rumelhart et al. (1987a), through a set of components and rules which are classified into eight major aspects:

1. a set of processing nodes,
2. a state of activation,
3. an output function for each node,
4. a pattern of connectivity among nodes,
5. a propagation rule for propagating patterns of activities through the network of connectivities,
6. an activation rule for combining the inputs impinging on a node with the unit's current state of that node to produce a new level of activation for the node,
7. a learning rule whereby patterns of connectivity are modified by experience, and
8. an environment within which the system must operate.

The broad structure of the general NNM is essentially a set of relationships between various processing nodes which represent different factors. These relationships are expressed in mathematical formulations which, due to lack of space, are not described here. More detailed information regarding the structure of the NNM can be referred to Rumelhart et al. (1987a).

Study Area

In accordance with the problem of conflicting land resource uses indicated by existing reports and documents (both private and public) and expert opinion, this study examines two specific problem areas. Figure 1 presents the study



Note: Number in the matrix: Number of Map Section

Figure 1. The Sub-Region of the Peace River Region

areas. The first study area (Area I) is part of Townships (TP) 85 and 86, and Range (R) 17, which is located east of the Beatton River. Lands in this area are mostly classified as high value woodland for forestry (BCMOLP&H, 1985). The second area (Area II) located further east represents a mixture of land uses including wetlands, preserved areas, forests and farmlands.

Data Requirements

The collection of data which incorporates various data sets from different sectors such as agriculture, forestry and environment, is a necessary step for land resource planning. Information about land resources, current land uses, and land use alternatives in the Peace River Region of British Columbia is available from a wide range of sources. However, comprehensive land data bases with a wide array of land use categories are uncommon. The existing land resource data sources tend to focus on one use such as agriculture, forestry or wildlife. These data bases were established by each Ministry or individual agency for its own needs. Such data sources limit land resource planning because of inconsistencies in scale and coverage. Commonly, when several data sources are used, the variety of scales and mapping units used pose problems of compatibility.

If the data are identified spatially, it is possible to estimate the land resource availability with a defined capability class in any specific location (Manning, 1988). Land resource data can then be related to particular sites or land units. Organizing and incorporating different data sets spatially from different resource sectors (agriculture, forestry and wildlife) has been of considerable importance. The key point is to choose a suitable spatial framework which allows for the integration of information from diverse sources.

There are several approaches with respect to the use of spatial units for analysis. The first approach is the use of administration units for data portrayal and integration. One of the problems in the use of this type of unit here was that only one administration unit existed in the Peace Region.

The use of ecological units (soils, climates, etc.) is another approach. There is significant biophysical information based on soil zones or climate zones available for the study region. However, socio-economic information is not always available on the same basis.

A third type of spatial unit is geometric grids where data are synthesized and reported by grids (sections or quarter sections). This approach is the most appropriate for this study. Information from various sources such as surveys, censuses, government agencies or ecological units can be modified to describe the grid units through the superimposition of various land resource maps. This procedure provides data with a broad array of land use categories.

In this study, the geometric units or map sections were used as the basic units for assessment. There were a total of 17 sections in the study area (see Figure 1); each section represents an unique area. Data on land resource availability, productivity, current land uses, yield, economic return, and habitat value for one section are different than those of another section.

The Simulator and Results

The experimental package was built on the Rochester Connectionist Simulator (RCS), version 4.1, which runs on the Unix environment and provides a graphic interface for Sun Microsystem workstations (Goddard, et al. 1988). This general purpose simulator (RCS) allows us to write C language code to construct the specific network connections and define the learning algorithm. We chose the standard sigmoid activation function and error-propagation function provided in the RCS Back Propagation Package. The learning procedure is firstly to use the input values to produce its own output values and then compare these outputs with the teaching values which were given by experts. If there were no differences, no learning would take place; otherwise, the weights were adjusted to reduce the differences (Rumelhart, et al. 1987b). The rule for changing weights used in this application was the generalized delta function, also provided in the RCS.

A neural net model which exhibits a hierarchical structure was designed. This model contained a multiplicity of land use planning by several land use objectives. Figure 2 illustrates the components and linkages of the model which consists of three layers: the input, hidden, and output layers. During the learning processing, an additional layer called the teaching layer was added for supervision purpose. This teaching layer contains the same number of nodes as those of the output layer.

At the input layer, there are 22 nodes, each of which represents a crucial factor which may affect land use decision making. Associated with each land unit are factors such as yields, net economic returns, soil erosion rates, habitat values, and areas of different land uses. Data on these factors for each land unit are required as inputs for the analysis.

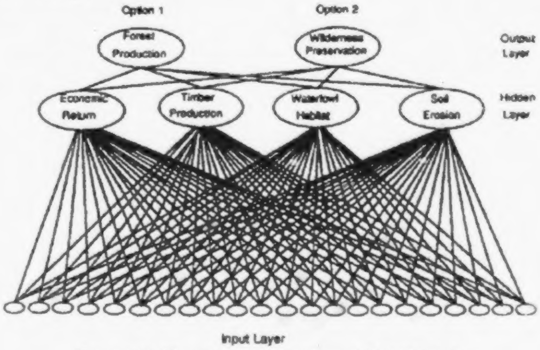


Figure 2. Structure of the Neural Net Model

The hidden layer of the model consisted of 4 nodes reflecting four land use objectives. Land use planning is often characterized by multiple objectives which are frequently in conflict. The measurement units of these objectives are almost always incommensurable. In this study, the land use objectives included: net economic return, timber production, habitat value, and soil loss by erosion. The objective functions were defined over these factors, which provided analysts with the required information to establish linkages between factor nodes and objective nodes.

In the presence of multiple objectives, one land unit which is suitable with respect to one objective may not be suitable with respect to another objective. For example, the attainment of economic return may sacrifice the attainment of the habitat protection objective. In multiple land use decision making, it is common that not all the objectives can be achieved simultaneously. Possible trade-offs or compromises between objectives have to be made in resource use planning (Cohon, 1978; Ignizio, 1982). These objectives are then used as decision criteria or standards by which the desirable land use option is selected for each land unit. This consideration provides the logical basis which links the objective nodes to the output nodes representing land use

Training patterns: Grid 2 for logging option; Grid 24 for preservation option.

	Trails	Logging-Value	Preservation-Value	Land Use Options
Test 1	G 26	323	675	*
	G 33	832	167	logging
	G35	416	596	*
	G28	569	439	*
	G 4	486	519	*
	G 3	427	576	*
	G 18	70	930	preservation
	G 25	133	868	preservation
	G 31	196	812	preservation

Training patterns: Grid 2 for logging option; Grid 24 for preservation option; and Grid 33 for logging option

Test 2	G 35	627	378	logging
	G 3	669	335	logging
	G 4	808	195	logging
	G 33	921	81	logging
	G 31	296	705	preservation
	G 25	300	702	preservation
	G 24	34	966	preservation

Training patterns: Grid 2 and Grid 33 for logging option; and Grid 24 and 31 for preservation option

Test 3	G 26	473	530	*
	G 31	495	509	*
	G 35	639	365	logging
	G 33	949	51	logging
	G 27	967	33	logging
	G 19	501	503	*
	(after another 500 cycles)			
	G 19	489	516	*
	G 13	240	763	preservation
	G 3	670	333	logging
	G 2	993	6	logging
	G 24	302	701	preservation
	(after another 500 cycles)			
	G 24	35	965	preservation

Note: G: Grid or Map Section; *: Uncertain

Table 1. Results of the Analysis

options. In this prototype study, the model structure was purposely kept simple. Only two land use options, forest production and wilderness preservation, were considered in the analysis.

The procedure of operating the neural net model for forest resource analysis began by training the net with a training algorithm. Prior to the training, it was necessary to consult with experts in forest resource management to identify two land units within which land use patterns represent the two typical options. In this case, map section 2 in area I and map section 24 in area II were chosen as examples of the two land use options.

Once the data files were set, input values were fed in parallel to the net. The net was trained by selecting some random weights and internal thresholds and then presenting all training data sequentially. The training algorithm repeatedly adjusted the weights after every trial using side information specifying the correct land use option until weights converged. The net was considered to have converged when outputs no longer changed on successive iterations, and one output of the last iteration corresponding the most likely land use option was high (maximum score of 1000), the other output was low (minimum score of 0). The output was then used directly as the restored memory.

Data files for eight land units in area I and seven land units in area II were presented for alternate trials, and the desired outputs were either 1000 or 0. Results of the analyses are listed in Table 1. All the outputs with input data files for land units in area I except that for grid 26 exhibited higher logging values and lower preservation values. These results indicate that land resources in this area were desirable for the forest production option. In grid 26, the forest production option and the preservation option scores were relatively close. This result could be attributed to the fact that many forest lands have been converted to croplands. The actual net outputs with inputs for area II show a different pattern, with lower scores for forest production option and higher scores for preservation option. Based on these results, most land units in area II should be preserved for wilderness area. Land use decisions for those land units with similar scores in both the forest use option and the preservation option are uncertain and require further investigation.

Concluding Comments

The preceding analysis with the neural net model has illustrated the potential of this technique in multiobjective forest use planning to generate alternative options. The exercise was prototypical in that only a small number of objectives and factors were specified and outcomes analysed. The neural net model is in an early stage of development. A more comprehensive analysis would include a much greater range of objectives, land use options or strategies, and factors affecting land uses. Nevertheless, the neural net model developed in this study provides a useful technique for forest resource management. Surprisingly, there have been very few practical applications of neural nets to date (Lippmann, 1987). Resource analysts show a lack of awareness regarding the potential of this technique for land use planning and management problems. Clearly, much more thought and effort must go into refining and designing new models for resource use planning.

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Artificial Intelligence and GIS: Tools to Implement Adaptive Resource Management

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Abstract
Adaptive resource management is a continual learning process that never converges to a state of equilibrium involving full knowledge and optimum productivity. In the design of adaptive management strategies, existing knowledge must be represented so that errors can be detected and used as a basis for further learning. In addition, the inherent uncertainty and risk surrounding possible future outcomes must be represented. Artificial intelligence techniques combined with GIS afford the opportunity to represent current knowledge and uncertainty. The blackboard approach to problem solving is reviewed. Blackboards provide a method to modularize and integrate various methods of representing knowledge, such as rules, cases, and models, along with representing uncertain knowledge. Because the knowledge about forestry and natural resources is often spatial in nature, a GIS should form the foundation of the blackboard. These concepts are being used in the design of a smoke management advisory system to assist in the planning and execution of prescribed burning operations.

Smoke Management

Prescribed fire is an indispensable part of forest management. It is used to treat approximately 6 000 000 acres (2 428 000 ha) each year in the South. Prescribed fire is used in the South to reduce hazardous fuels, dispose of logging debris, prepare sites for seeding or planting, improve wildlife habitat, manage competing vegetation, control insects and disease, improve forage for grazing, enhance appearance, improve access, and perpetuate fire-dependent species (Wade and Lunsford 1989). Yet along with the many benefits of prescribed fire, smoke is produced.

Smoke from a prescribed fire can adversely affect health, visibility, and highway safety. The risk is greatest from fires which emit large amounts of smoke for extended periods of time. Most understory prescribed burns and broadcast burns are 'self-extinguishing', that is, smoke sources are extinguished within a few hours of ignition. Thus, these prescribed burns tend to cause fewer problems than either piled debris burning or wildfires. Pile burning and wildfires can result in extensive smouldering combustion that provides a smoke source for many hours or days. A long-lived smoke source greatly increases the risk of encountering meteorological conditions which fail to disperse the smoke adequately, direct the smoke over populated areas and roadways, or enhance the probability of extremely low visibility in smoke and fog. Such conditions cannot be reliably forecast over periods greater than 36 hours. The risk of an errant forecast exists for even shorter time periods.

The results of decreased visibility on roadways from smoke, often in combination with fog, have occasionally been tragic. In November 1983, 3 people were killed and 7 injured in a highway accident involving forestry smoke on Interstate I-10 in the Florida panhandle. Those involved in the accident filed suit for $21 million. On December 31, 1988, forestry smoke was implicated as a cause of near-zero visibility along a 30-mile stretch of I-95 near the Kennedy Space Center in Florida. The result was 12 separate accidents involving 45 vehicles with numerous injuries but fortunately no fatalities.

Responsible forest management utilizes prescribed fire while attempting to mitigate the negative impacts of smoke through smoke management. Smoke management tools (Southern Forest Fire Laboratory Staff 1976, National Wildfire Coordinating Group 1985) have been designed to avoid violation of the Clean Air Act and its amendments that mandate air quality standards. Neither the standards nor available management tools directly address the effect of forestry smoke on visibility and highway safety. Over the past 15 years, roadway safety problems associated with smoke have been identified as a major obstacle to the continued use of prescribed fire as a forest management tool in the South.

Predicting the impact of smoke on highway visibility is a complex problem. Systems analysis, the study of the behavior of, and interactions among, components in a model of a complex system, provides a useful methodology to address the problem. Initially, the highway visibility problem can be broken into four components: combustion, emissions, dispersion (diffusion), and visibility. The combustion process produces a certain amount of smoke which disperses through the atmosphere, interacting with the background conditions, and resulting in a certain level of visibility. These four components or subsystems can be further subdivided.

There are two aspects of combustion, flaming (associated with the flame front) and smouldering (or glowing). Most, if not all research on fire behavior (e.g., rate of fire spread and fire intensity) has concentrated on flaming combustion. Unfortunately, smouldering combustion makes a major contribution to smoke production. There is a paucity of information on smouldering combustion. Additional research or rules of thumb based on experience must be developed to account for residence time, smouldering combustion, and piled debris burning.

Given information about fuels and combustion, the emission rate can be estimated. Although some research has been done on emissions, there are significant gaps in current knowledge. Given information on the emissions, fire intensity, and weather, the dispersion of smoke can be estimated. A plume model (e.g., Peterson and Lavdas 1986) can be used to estimate smoke concentrations downwind of the source. Models require simplifying assumptions. Given information on dispersion, weather, and the current condition of the atmosphere before the addition of smoke (background), visibility can be estimated.

This cursory analysis of the smoke problem indicates that existing knowledge is incomplete and uncertain. In light of this, what is the best way to manage the forest so that prescribed fires can be used to meet various objectives while minimizing the risk of highway safety problems due to smoke? This paper proposes that there are two essential ingredients to address in the smoke problem, and most other natural resource management problems: 1) a landscape ecology perspective and 2) an adaptive management approach. GIS provides a landscape perspective, while GIS and elements of artificial intelligence (AI), specifically, the construction of knowledge-based systems, provide a means to implement adaptive resource management.

Landscape Ecology

Forman and Godron (1986) state that a landscape is a distinct, measurable unit defined by its recognizable and spatially repetitive cluster of interacting ecosystems, geomorphology, and disturbance regimes. Landscapes may be classified along a gradient, from natural landscapes, to production landscapes such as timber, range, and agricultural landscapes, to urban landscapes. GIS provides a landscape perspective. With the proliferation of GIS software, the landscape viewpoint will become increasingly prominent.

Landscape ecology focuses on three characteristics of the landscape, structure, function, and change. Landscape ecology studies both the principles concerning structure, function, and change, and their application to the formulation and solving of problems (Forman and Godron 1986).

All landscapes share a common structure of patches (an area differing in appearance from its surroundings), corridors (narrow strips of land which differ from the matrix on either side), and background matrix (a surrounding area that has a different species structure or composition). Many disturbances mold the structure of a landscape. They include natural events such as hurricanes, fires, and pest outbreaks, and human interventions such as plowing, logging, and spraying. Each ecosystem type has a distinctive disturbance regime, that is, the intensities, frequencies, and types of disturbances that occur. In the language of landscape ecology, prescribed fires from patches produce smoke which can drift across corridors, such as highways. Management of the disturbance regime (patch dynamics) requires the use of prescribed fire. Transportation along road corridors should be safe.

Function refers to the flows of energy, mineral nutrients and species, while change refers to the alteration in structure and function over time. Change is the norm in both landscape elements and landscapes. Change implies uncertainty. The single greatest difficulty in managing most landscapes is lack of knowledge of the forces that underlie landscape change (Forman and Godron 1986). A systems analysis approach is often undertaken in an attempt to understand landscape change. Thus, systems analysis and modeling are important parts of landscape management (Forman and Godron 1986). Many types of maps may be used to manage landscapes and it is also possible to build models from these maps. Risk assessment is one of the most useful applications of modeling. Adaptive resource management (modeling the current state of knowledge, making mistakes, and adapting the models to learn from the mistakes) provides an effective means of coping with change and the resulting uncertainty.

Adaptive Resource Management

Adaptive resource management uses the construction of dynamic models as an intellectual device to help people clarify issues, communicate effectively about shared concerns, and explore objectively the consequences of alternative policy options (Holling 1978, Walters 1986). Adaptive policies call for variation and change as essentials to learning. Management is a continual learning process that evolves by learning from mistakes. Yet, it is not simply trial and error. Current knowledge guides future discovery. Actively adaptive, probing, deliberately experimental policies should be a basic part of renewable resource management (Walters 1986).

Designing adaptive management strategies involves:

1) defining and bounding management problems in terms of objectives and constraints,
2) representation of existing understanding so that errors can be detected and used as a basis for further learning,
3) representation of uncertainty and its propagation through time in relation to management actions,
4) design of balanced policies that provide for continuing resource production and protection while simultaneously probing for better understanding and untested opportunity (Walters 1986).

There are formidable obstacles to practical implementation of adaptive resource management. Knowledge-based systems can help overcome those obstacles. Saveland (1989) explored how a knowledge-based system could represent existing understanding and uncertainty in the design of balanced policy for a wilderness fire management problem. The remainder of this paper focuses on the representation of existing knowledge and the representation of uncertainty in order to balance the need for prescribed fire with the need to minimize the nuisance of smoke. Integrating the various representations can be accomplished with a blackboard.

Representing Existing Knowledge

One of the primary goals of knowledge-based systems is to represent current knowledge. Several methods are used to represent knowledge, among them rules, cases, and models.

Rules

The first knowledge-based systems represented knowledge as rules. Thus, rules have a relatively long history and are firmly entrenched. Even though they have several limitations, rules are currently the most popular and widespread method of representing knowledge. Rules take the familiar form of IF something is true, THEN draw a conclusion or take action (Stock 1987). For example,

If the Keetch-Byram Drought Index (Keetch and Byram 1968) is less than 400, then there will not be much ignition and smoldering of large fuels.

There are already several efforts to link rule-based knowledge systems with GIS. CLIPS has been linked to GRASS by Spectrum Sciences & Software and by researchers at Texas A&M. USGS researchers plan to link Neuron Data's NEXPERT/OBJECT with ARC/INFO. Coughlan and Running (1989) are also reported to be linking a rule-based system to a GIS. There are probably other efforts too.

Cases

Case-based reasoning (CBR) is used by people or computers to solve new problems by adapting solutions that were used to solve previous problems (Hammond 1989, Kolodner 1988, Riesbeck and Schank 1989). In other words, a case-based reasoner (human or machine) finds those cases in memory that solved problems similar to the current problem, and adapts the previous solution to fit the current problem, taking into account any difference between the current and previous situations.

There are two key issues in CBR: retrieval and adaptation. The most appropriate case to adapt must be retrieved from memory, even when the case may share few superficial features. Adaptation consists of making the right changes to resolve differences between the retrieved case and the current situation.

Prescribed burn plans provide a written record of past prescribed fires. A computerized historical record (case library) of prescribed burns will be developed as part of the smoke management system.

Models

Walters (1986) uses models to represent current knowledge in his formulation of adaptive resource management. The use of models to represent so-called 'deep knowledge', as opposed to the 'surface knowledge' represented by rules, is receiving increasing attention in AI. Models either have been constructed or are being constructed for the four components (combustion, emissions, dispersion, visibility) of the smoke management system. Dispersion or diffusion models are intrinsically spatial. Smoke drift, fire spread, insect outbreaks, oil spills, etc., are all examples of diffusion processes. GIS should provide a major contribution to dispersion or diffusion modeling.

Models will be used in the smoke management system to the extent we understand the underlying processes of combustion, emissions, dispersion, and visibility. Rules of thumb based on experience will fill in where models are incomplete.

Representing Uncertainty

There are a variety of ways to represent uncertainty (Kanal and Lemmer 1986). How best to represent uncertainty is a hotly debated topic in the AI literature. There are essentially three schools of thought on how to handle uncertainty (Pearl 1988). One approach is to use non-numeric techniques, for example, the development of non-monotonic logics (e.g., McDermott and Doyle 1980, Reiter 1980). Formally, non-monotonic logical systems are logics in which the introduction of new axioms can invalidate old theorems. They come into play when assumptions are made and subsequently revised in light of new observations. A second approach is to make extensive use of probability theory, such as a Bayesian approach. Until recently, one of the major drawbacks to a Bayesian approach was the computational difficulty of arriving at probabilities. Bayesian belief networks (Pearl 1988) are removing many of the computational difficulties. A third approach attempts to overcome the computational complexity by inventing new calculi, for example, fuzzy logic (Zadeh 1965), Dempster-Shafer belief functions (Dempster 1968, Shafer 1976), and certainty factors (Shortliffe and Buchanan 1975). Since certainty factors fit nicely with rules, they are firmly entrenched. Yet, they are probably the weakest form of reasoning about uncertainty.

Each method has strong points and weak points. Walters (1986) used Bayesian methods in his formulation of adaptive resource management. We are looking to incorporate Bayesian methods in the smoke management system because of the strong theoretical foundation, the power of conditional probability statements, and the growing tractability of computations (Lauritzen and Spiegelhalter 1988), and because of the so called 'Dutch book' argument. The Dutch book argument shows that a gambler deviating from the rules of probability calculus will, in the long run, lose against an opponent who adheres to those rules.

Putting It All Together On The Blackboard

Blackboards (Engelmore and Morgan 1988, Hayes-Roth 1985, Nii 1986a, Nii 1986b) provide a means to integrate different representations of knowledge. For example, Rissland and Skalak (1989) combine rule-based and case-based reasoning. In blackboard systems, a problem is decomposed to maximize the independence of the subsystems. This, in turn, provides maximum flexibility in software development. There are three major components to blackboard systems: knowledge sources, blackboard data structure, and a control mechanism. Knowledge sources are separate and independent. Mathematical models, simulation models, relational databases, and GIS can be knowledge sources. Knowledge-based systems that use rules, cases, or models can also be knowledge sources. The blackboard data structure is a global database. Knowledge sources produce changes to the blackboard that lead incrementally to problem solutions. In a pure blackboard system, the control mechanism is such that knowledge sources respond opportunistically to changes in the blackboard. The following analogy further describes a blackboard system.

> "Consider a hypothetical problem of a group of people trying to put together a jigsaw puzzle. Imagine a room with a large blackboard and around it a group of people each holding over-size jigsaw pieces. We start with volunteers who put their most 'promising' pieces on the blackboard. Each member of the group looks at his pieces and sees if any of them fit into the pieces already on the blackboard. Those with the appropriate pieces go up to the blackboard and update the evolving solution. The new updates cause other pieces to fall into place, and other people go to the blackboard to add their pieces. The whole puzzle can be solved in complete silence; that is, there need be no direct communication among the group. The apparent cooperative behavior is mediated by the state of the solution on the blackboard. If one watches the task being performed, the solution is built incrementally (one piece at a time) and opportunistically (as an opportunity for adding a piece arises), as opposed to starting say, systematically from the left top corner and trying each piece.
>
> This analogy illustrates quite well the blackboard problem-solving behavior implied in the model. Now let's change the layout of the room in such a way that there is only one center aisle wide enough for one person to get through to the blackboard. Now, no more than one person can go up to the blackboard at one time, and a monitor is needed, someone who can see the group and can choose the order in which a person is to go up to the blackboard. The monitor can ask all people who have pieces to add to raise their hands. The monitor can then choose one person from those with their hands raised. To select one person, some criteria for making the choice is needed. The monitor needs a strategy or a set of strategies for solving the puzzle. The monitor can choose a strategy before the puzzle solving begins or can develop strategies as the solution begins to unfold. In any case, it should be noted that the monitor has

> broad executive power. By adding the constraint that solution building physically occur one step at a time in some order determined by the monitor (when multiple steps are possible and desirable), the blackboard model is brought closer to the realities inherent in serial-computing environments." (Nii 1986a).

The final solution for the smoke management system will include a map with the likelihood of various smoke concentrations downwind of the prescribed fire. The blackboard will contain the evolving map as a solution is developed. The need for GIS is obvious. The blackboard will also contain the concept of likelihood, using Bayesian techniques. Knowledge sources will include rules, cases, and models for each of the four components (combustion, emissions, dispersion, visibility).

Summary

The need for prescribed fire in managing forest patch dynamics must be balanced against the need for safe travel along road corridors. Landscape ecology provides the appropriate perspective and emphasizes the important role of change. Adaptive resource management provides an effective means to manage change by requiring the representation of current knowledge and the uncertainty surrounding that knowledge. GIS provides the landscape perspective and tools for developing spatial models. AI, specifically knowledge based systems, provides the tools to represent current knowledge, such as rules, cases, and models. AI also provides a variety of ways to represent uncertainty. Blackboard systems provide a mechanism to integrate AI and GIS to develop adaptive resource management strategies.

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Natural Language Interface to Geographic Databases. Experiments with Intelligent Assistant

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Abstract

Natural Language Systems (NLS) permit interactions with computer systems in the language and syntax native to the computer operator. These types of interfaces, integrated with complex information systems, could potentially not only raise the efficiency of system use, shorten the training time, and allow for the more precise formulation of queries but also facilitate such system operations as updates, searches, selecting, and generation of reports. Very few publications are available on NLS interfaces to geographic information systems. This paper evaluates the natural language system interface, Intelligent Assistant, to a database containing spatially referenced information in terms of user's input, query formulation, query interpretation by the system and system efficiency. Queries directed to NLS are paralleled on the GIS system to the same database. The comparison between an interface with a command query language and with the NLS interpreter is given. The steps involved in using NLS are explained and demonstrated. Interactive sessions with the system are discussed in detail. Finally, time estimates required for parsing of queries by NLS are provided to allow for the estimation of NLS efficiency.

1.0 Introduction

Effective use of information systems depends largely on the ease with which these systems can be accessed by the user (Petric, 1976, Krause,1980). There are several ways in which the access may be simplified. One way is through a natural language interface.

The objective of this paper is to present and evaluate a natural language interface to an information system containing spatially referenced data. The emphasis is on practical aspects of the interaction with a natural language computer front-end. Examples illustrate the process of the lexicon development for the database, the handling of queries with errors, clarification dialogue, and the handling of ellipses. Information on the speed of parsing is given so one may evaluate any extra time required to process natural English commands. References to literature provide some insight into the most recent developments in natural language systems. The authors hope that reading this paper will answer the question "What would a GIS with natural language front-end look like?"

2.0 Natural Language Interfaces

A natural language interface allows the user to interact with the computer system in the user's native language. Using NLS, instead of querying the GIS system with the dialogue:

GIS: RESELECT BASEMAP POLYS LINE = 3
GIS: ARCS BASEMAPE

the user asks:

NLS: SHOW ME ALL THE PRIMARY ROADS ON BASEMAP

(primary roads have code class = 3)

Several examples of natural language interfaces to information systems can be found in the literature. Hendrix (1977, 1978) discusses the NLS interface, LIFER , to a naval database. Excellent examples of queries of a spatial information database are discussed by Lenhert et al (1980) in her paper on EXPLORER, an NLS front-end for oil exploration systems. Waltz (1978) described PLANES, an NLS interface to an aircraft flight database. More recently, Samad (1986) presented details of CLEOPATRA, an NLS to CAD interface.

2.1 Basic Concepts

An NLS interface, by accepting commands entered in conversational English, allows system use by people without extensive training in computers (Egenhofer et al, 1988).

The advantage of NLS over the system query language is that with NLS the user is exempted from understanding how and what the computer system does. The user may be unfamiliar with the logical structure of the database or with the syntax of the system query language. The user must only know what he wants to retrieve from the system. He does not even have to be correct in typing his request as the NLS interface should be able to handle both imprecise queries and syntactic and spelling errors.

As there is no complete model for the natural, spoken, unbounded language, existing natural language interfaces have been operating on a subset of English, known as restricted English. The question of what is easier to learn, a restricted natural language or an artificial query language, has not yet found a decisive answer (Napier et al, 1989, Samad, 1986). The question of benefits from the use of NLS interfaces is also not clear. Most researchers agree, however, that the problem is not in the concept itself but in the limitations of existing technologies. Krause (1980), Larson (1983), and Napier et al, (1989) indicated some advantages of the use of restricted natural language interfaces with databases or spread sheets. This research did not answer conclusively for what type of users and applications NLS interfaces are superior to other types of computer-user communication models. Despite all those problems, there is a definite trend to provide, as an option, NLS interfaces to commercial information systems, in particular with DDS or EIS (Larson, 1983, Meador, 1986).

Most NLS described in literature are query and answer systems to non-spatial databases. Few papers can be found on actual examples of NLS to geographic information systems (Bolc, 1984, Kasturi, 1989). Spatial information systems, because of their diverse functionality (Barrera et al, 1981) and complex relationships among database elements would call for much more sophisticated interfaces than those existing ones.

NLS interfaces to spatial information systems may be implemented as the interface to all or some of the system modules. NLS query and answer interfaces to GIS databases would resemble existing natural language interfaces. NLS providing access to GIS modeling capabilities and report and map generation functions would require new capabilities to handle tasks not found in non-spatial databases. An interesting aspect of the use of natural languages in geographic information systems was pointed out by Robinson(1985); he suggested that NLS interfaces may be the best suited tool to handle the fuzziness intrinsic to geographic queries and spatial information.

To sum up, proponents of the use of natural language systems argue that NLS offer the unique flexibility in query formulation, cut down on learning time, do not require translation of problems from 'domain specific' language into a highly-constrained computer query language, and is potentially one language for all the system (Samad, 1986). The opponents of the NLS interfaces, as for example Hill (1983), argue that the inherent ambiguity of natural languages excludes this class of languages from use in analytical tasks. Some argue also that the verbosity of natural language renders NLS ineffective.

3.0 Intelligent Assistant, an NLS Interface to Q&A Database.

Interaction with a geographic database through a natural language system, Intelligent Assistant (IA), will be discussed.

Intelligent Assistant is the natural language interface to Q&A database, an integrated database manager for PC class microcomputers. Using Intelligent Assistant, one can interact with the system using the natural, spoken subset of English. IA allows for record retrieval, the production of tabular reports, mathematical calculations, the creation of new data records and the update of multiple records.

Q&A is not the GIS system. It does not have graphic capabilities nor GIS modeling functions. Q&A is used here as the host of a geographically referenced database and as the shell for a natural language interface. The database implemented in Q&A was extracted from the polygon attribute file of ARC/INFO. To assure the parity of queries on IA with the ARC/INFO query language, the queries on Q&A were paralleled with queries on ARC/PLOT and INFO systems.

The initial step in using the Intelligent Assistant consists of loading IA with information about the database (Edwards, 1986, Hendrix et al 1978). This teaching process must supply the IA dictionary with information on database content, synonyms for items names, adjectives and verbs to be used in queries and synonyms by which the users wishes to query database content.

The query process, using IA, has two phases. In phase one, the system parses the query typed in by the user. The system checks the query against its lexicon and mistakes are flagged out. The user has a choice of correcting the mistake, or, if it was only a word unknown to IA, the user may add this word and its synonyms to the system dictionary. The user may also force the system to come up with its own interpretation of the misspelled, unknown word or the whole phrase. In phase two of the query processing, after parsing, the system provides its interpretation of the request. Here again, the user may accept it or stop the query.

For example, the conversation with IA may look as follows:

USER INPUT:
Show me, if th are any polygons with area between 2000 and 5000 and with moisture limitations.

IA ASKS FOR THE CORRECTION OF "th"

when corrected to "there" IA provides the interpretation of the query:

POLYGONS WITH AREA > = 2000 AND <= 5000 AND AGRO-CLIMATE CONTAINS A

If this interpretation is accepted, the system retrieves information on polygons that satisfy the selection criteria.

4.0 Experiments with Intelligent Assistant

The database used in this experiment contains information about Agro-ecological Resource Areas of Alberta and is taken from the work of Pettapiece (1989). The polygon map of agro-ecological resource areas was digitized and set up as a coverage on ARC/INFO. Information related to polygons was encoded in an INFO table and related to the coverage PAT file. Examples of the attribute file which was used in IA queries are given in Table 1. This file contains information on areas of the polygons, polygon ID, names of the regions, names of the agro-ecological resource areas, IDs for the areas, types of landform,s types of soil, texture, and agroclimatic limitations for each polygon.

4.1 Customizing the NLS Lexicon

IA's standard lexicon contains some 400 basic words of general applicability (see Table 2). To handle queries to the database, the NLS dictionary must be expanded to include words and expressions specific to the database. This teaching process, known as customizing, is carried out in two steps. In step one, synonyms for item names are coded into the system. In step two, synonyms that describe database content are supplied to the system dictionary. Examples of synonyms for item names are given in Table 3. Synonyms referring to database content are much more difficult to implement, they must express the meaning of sometimes complex coding schemes of items in the database. They must also reflect the language by which the user searches for particular database elements. Problems related to the implementation of the proper subset of expressions are both of technical and lexical nature. On one hand, one must think of the language the user will use to query the database. On the other hand, the system itself is imposing limitations on the length and complexity of admissible synonyms. In the experimental database, it was impossible, therefore, to implement the full phrase:

AREA	POLY ID	REGION	AREA-NAME	LANDFORM	TEXTURE	SOILS	AGRO-CLIMATE
172643.549	2.	Western Uplands, foothills	Mountains	UNLC	UNCL	UNCL	UNCL
9369.168	3.	Clear Hills - Zama	Zama Lake	L(U)	C(CL)	GL-O•	4H
5001.187	4.	Clear Hills - Zama	Caribou Mountains	M	CL	GL-O	5H
15725.415	5.	Manning - High Level	High Level	L(U)	SIC-SIL	GL(SO,O)	3H(4H)
2348.261	6.	Manning - High Level	Fox Lake	U	S(L)	O-BS(GL)	3H
10540.763	7.	Clear Hills - Zama	Rainbow Lake	U(H)	CL-SIC	GL-O	4H
2633.464	8.	Fort Vermilion	Boyer River	U	SL(S)	GL(BS,O)	2AH
2034.713	9.	Fort Vermilion	La Crete	L(U)	SIL-CL	GL(DG)	2AH
2447.619	10.	Clear Hills - Zama	Milligan Hills	H	CL	GL(O)	5H
6186.777	11.	Calling - Peerless	Otter Lakes	H-U	CL(SL,C)	GL(O)	4H-5H
6636.840	12.	Manning - High Level	Manning	L	C-SIC	SO(GL-DG)	3H
11204.989	13.	Clear Hills - Zama	Clear Hills	H(S)	CL	GL(O)	5H

Table 1. Sample of database implemented on Q&A system.

DISPLAY	CALCULATE	SEARCH/SORT
DISPLAY	AVERAGE	AND
GET	COUNT	BEFORE
LIST	MAXIMUM	BETWEEN
SEARCH	MINIMUM	CONTAINING
SHOW	SUM	GREATER
	TOTAL	HIGHEST
		OR
		NOT
		LARGEST

Table 2. Examples of built-in vocabulary for Intelligent Assistant.

ITEM NAME	SYNONYMS
AREA	SIZE
ID	POLYGON NUMBER; POLYGON; POLYGON ID; ZONE
REGION	AGRO-ECOLOGICAL REGION
AREA-CODE	AREA ID
AREA-NAME	AGRO-ECOLOGICAL RESOURCE AREA

Table 3. Examples of implemented database items and their synonyms.

SYNONYM	MEANING
50% mix of classes	CONTAINS -
Clays	TEXTURE = C
Containing silt	TEXTURE CONTAINS SI
Heat Limitations	AGRO-CLIMATE CONTAINS H
Mainly hummocky uplands	TEXTURE BEGINS WITH H
Mainly level plains	LANDFORM BEGINS WITH L
Moderate heat limitations	AGRO-CLIMATE = 2H
Moisture limitations	AGRO-CLIMATE CONTAINS A
Out of arable agriculture	AGRO-CLIMATE = 5H
Severe Limitations	AGRO-CLIMATE CONTAINS 4
Slight limitations	AGRO-CLIMATE CONTAINS 2
Slopes > 15%	Landform = H(S);H-S;H(S);S(H)

Table 4. Examples of synonyms for the tested database.

" Hummocky uplands or hill lands with slopes of 5-15% "

as the synonym of the code "H". Instead the phrase was broken up into three components with the same interpretation:

Hummocky uplands — hill lands — slopes of 5-15%

It was also impossible to implement the synonym:

Hill lands — Hummocky uplands and Hill lands

as the system went to recursive substitution.

Examples of implemented synonyms are given in Table 4. Synonyms determine how someone may query the database. Thus, the selection of synonyms should be done after the user's 'language' is studied. In addition to synonyms for items, synonyms that are related to verbs, adjectives and adverbs used in the queries should be supplied to the system. They make the conversation with NLS look more 'natural'. Only a few synonyms in this group were implemented in this exercise.

4.2 Queries

To test the effectiveness of the NLS interface and to demonstrate interaction with the GIS database, several queries of the agro-ecological resource areas attribute file were performed. Some of these queries are given in Table 5 and Table 6. Table 6 provides examples of queries in ARC/PLOT or INFO language parallel to NLS queries. Those queries were directed to the same database located on ARC/INFO.

(1) Where are zones with mainly spteeplands ?
(2) Show polygons with severe climatic limitations.
(3) Show polygons with area greater than 3000.
(4) How many areas have slight moisture limitations.
(5) What is their total area.
(6) Where is the largest polygon with severe heat limitations.
(7) Show agro-ecological resource areas with slight moisture limitations.
(8) What is the total area of polygons with slope > 15%.
(9) What is the average size of polygons with slight moisture limitations.
(10) Is there any polygons with area between 2000 and 5000 and moisture limitations with silt.
(11) Display region area-name for agro-ecological resource areas with silt and two or more landforms predominantly undulating sorted by area-name and region with heat limitations and with area not greater than 6000.

TABLE 5. Examples of queries of the test database.

4.3 Handling of Errors

NLS response to two types of errors in the queries was evaluated: spelling errors and grammatical errors. The following questions were given:

(a) Show polygn greter than 3000.

and

(b) Llust polygons in descending ordr soted has texture contains Si.

NLS query no	ARC/PLOT
1	Reselect Alara polys landform = H
2	Reselect alara polys agro-climate CN4
3	Reselect alara polys area GT 3000
4	Reselect alara polys agro-climate in {'2A', '2A-2H', '2S(2H)'}
8,9	INFO report
11	Reselect alara poly texture = SI and (landform CN - or landform CN ( ) and agro-climate CN H and area LE 6000

Table 6. ARC/PLOT queries parallel to NLS queries from Table 5

In case (a), the system allowed for corrections of "polygn" and "greter" and "then". If, instead, the system was forced to accept the input as it was, the following interpretation of the query was given:

SELECT all polygons with area = 3000

The error in "then" was interpreted as an error in "greater" even when "greater" was correctly spelled.

In case (b), after corrections in "soted", with uncorrected syntax and errors in "Llust" and "ordr" the system correctly interpreted the request.

4.4 Handling of Ellipses

To demonstrate handling of ellipses by IA, the following dialogue was performed:

Select areas with clay.
Display them in alphabetical order.

Several ellipses of this type were tested and were handled properly by the system.

4.5 Parsing Time

Parsing time of queries was tested on several simple and complex examples (Table 7). It ranged from 4 seconds for the simplest (one attribute condition) query to 24 seconds for the complex one (more than two restrictions on attributes). On the basis of several tests the parsing time, for the error-free questions of typical complexity is about 6 to 10 seconds. The parameters for the PC system on which Intelligent Assistant was installed are given in Appendix 1.

5.0 Conclusions

Natural language-based interfaces offer an interesting alternative to command query languages, object icon-type interfaces, menu-driven systems or form fill-in interfaces (QBE) (Napier,1989). NLS interfaces seem to be particularly suited to systems where queries are initially formulated in domain-specific, not artificial, language and the potential user of the system is not well trained in formal database design and system use. These features are characteristic of geographic information systems.

Ease of use of an NLS depends on the ability of the NLS engine to handle complex linguistic forms and on the ease with which NLS may be adapted to the particular application. The process of teaching NLS the knowledge necessary to handle user's input may be discouraging and expensive, especially for dynamic databases.

GIS systems would certainly benefit from having, as an option to menus and a command language, an NLS interface. With a trend toward SQL in GIS systems, implementation of an NLS via SQL may not be too distant. An NLS interface accessing other than query and retrieval functions of GIS systems may require more research into linguistic aspects of GIS dialogue. Research into natural languages may also stimulate the development of algorithms to handle fuzzy requests of the type " near", "close", " not too far", and "in the vicinity".

Experiments described in this paper demonstrated the steps involved in the use of NLS systems. The NLS systems available now require some preliminary work that may be discouraging. The process of formulating queries using NLS allows for the retrieval of database items (polygons) without knowing how they were coded. In case of the database presented, it was of particular importance, since the coding scheme was quite convoluted. The formulation of complex queries with several conditions or requests for summary reports was much simpler with NLS than with the GIS query language. Using Intelligent Assistant, the polygon attribute file could have been queried by someone without knowledge of how the items were coded or how the system works. The user does not have to know the name of the 'coverage' with data, does not have to know what type of coverage it is or what are the names of items he is searching for. The parsing time for queries is quite short so it may be disregarded as a source of problems. Ability to handle

Question	Parsing Time (sec)
Show polygons with severe limitations	5
Show polygons with severe limitations and with area less than 10000.0	7
List AREA-NAME where area is less than 5000.0	4
List AREA-NAME where area is less than 5000.0 and more than 2000.0	7
If there is any polygon with area between 2000 and 5000 and with moisture limitations with with silt	10
Display region area-name for agro-ecological resource areas with silt and two or more landforms predominantly undulating sorted by area-name and region with heat limitations and with area not greater than 10000.0	24

TABLE 7. Examples of queries and related parsing time.

errors in the input request seems to add a lot of 'friendliness' to the system.

The natural language interface presented in this paper did not differ from the NLS supplied to non-spatial databases. Thus, issues specific to GIS such as mentioned fuzziness of GIS queries, an expanded lexicon to handle commands and operations available on GIS systems, access to map generation functions were not reviewed or tested here. The problem of the use of natural language interfaces to computer systems is still open, but may be this paper will stimulate the research in NLS interfaces to geographic information systems.

Acknowledgement

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Appendix 1

Specifications of the PC system on which the Q&A test was carried out.

PC 8088 class machine, DOS 3.3, hard drive 20MB

Norton Computer index	(CI) related to IBM/XT 1.0
Norton Disk Index	(DI) related to IBM/XT 1.7
Norton Performance index	(PI) related to IBM/XT 1.2

Data Transfer to/from hard disk 161.3 Kb/sec
Random seek; average access time 61.0 ms
Track-to-track seek; track to track access time 14.1 ms

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Automated Labeling System for the Alberta Vegetation Inventory Project

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Abstract
This paper describes an implementation of an automatic label placement system for thematic data. This system was designed for a specific mapping project utilizing both the INTERGRAPH graphic system and ARC/INFO GIS system. Initially, a raster data model is created from several single variable files built through ESRI's ARC/INFO rasterization. The set of all possible label placement locations is defined and searched using heuristics. As the final result, all placeable labels are correctly positioned, either inside the polygons or outside with text leaders added where necessary. Labels for which no locations could be found within known constraints are clearly marked for operators attention.

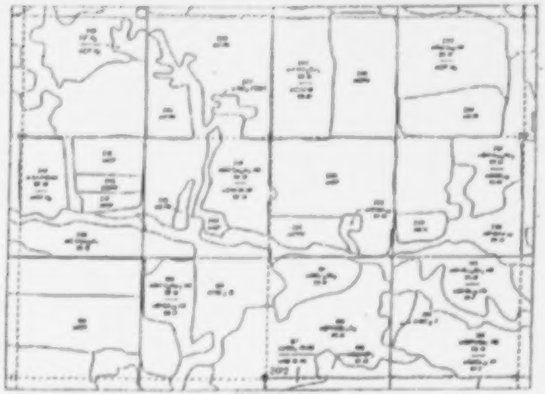

Figure 1

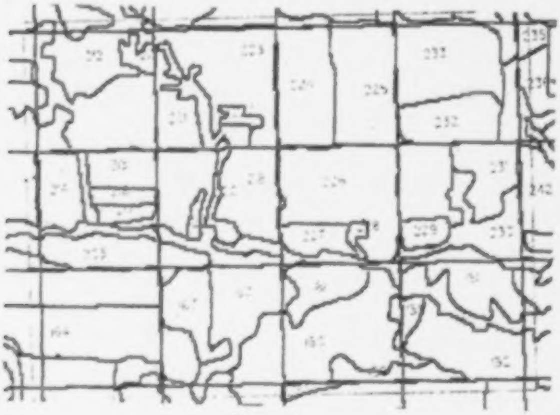

Figure 2

2.3 Raster Model Analysis

Initially the approximate distance from the constraining borders (map edge, polygon boundary, ATS line) for every grid cell in the raster model is calculated. From a set of cells known to belong to one polygon, the centre, most optimal text location is selected. Each polygon range is also calculated and stored.

2.4 Text Placement Phase

The preferable locations for the labels and possible text leaders are defined through analysis of the raster model. The general approach is to place all labels that fit inside the associated polygons at centre locations to form the starting partial solution. A map of coarse grid cells is superimposed and each cell is analyzed for it's local free space areas. Selected points are stored as potential label locations. Figure 5 presents these points for a selected area. For all non-labelled polygons, the list relating polygons with possible location points in grid cells is created. Another list defines density of the possible grid utilization reflected by a number of polygons competing for the label location inside a given cell. Utilizing heuristics and the mentioned lists, the system places as many labels as possible. Its primary rule is to place the label with a smaller degree of freedom before a label with a larger degree of freedom in a grid cell with the

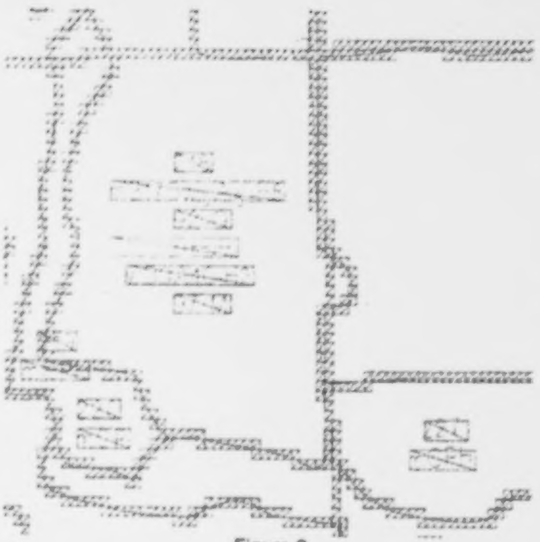

Figure 3

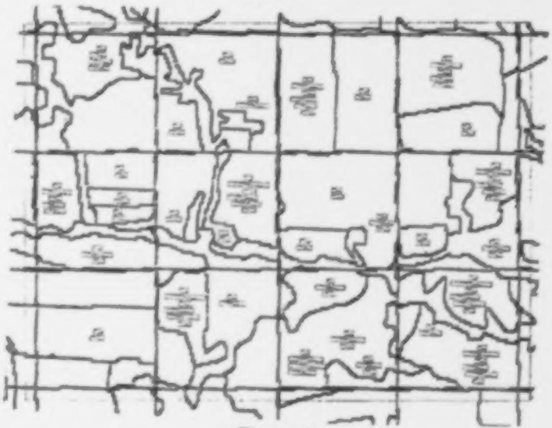

Figure 4

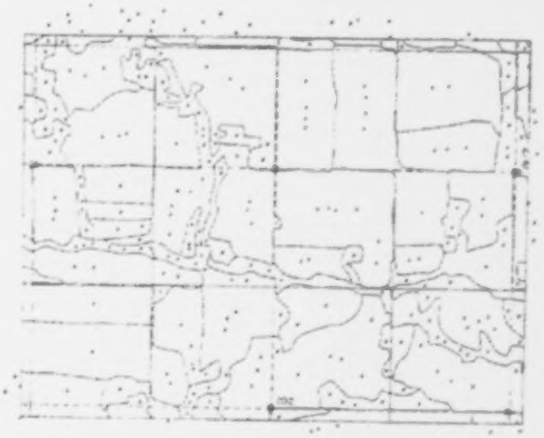

Figure 5

smallest density. The intermediate solution is analyzed for completeness. If necessary and possible, labels already placed are reorganized inside a grid cell; otherwise, previously placed labels are removed to a new location. A heuristic controls rating and selection of label positions. Different possible label locations are evaluated according to the pre-defined user criteria.

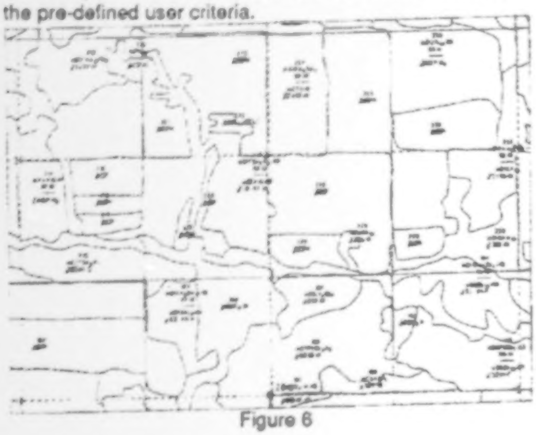

Figure 6

2.5 Text Node Modification

The text node locations, and colour, in the INTERGRAPH graphics file are changed according to information calculated in the text placement phase. Figure 6 illustrates the initial text node locations (internal points manually digitized). The location of the text node for polygon 163 was chosen with an average size label in mind. In fact, it is not a correct location for it's label. Also, the polygon 152 text node is not accurately positioned, but for a different reason. The ATS lines are not considered at the time of digitizing, but they limit the available space for labels.

Figure 7 displays the updated text node locations with label information calculated by the Automated Labeling System. A different colour is used to mark nodes/texts that could not be correctly placed automatically and require graphic operator attention.

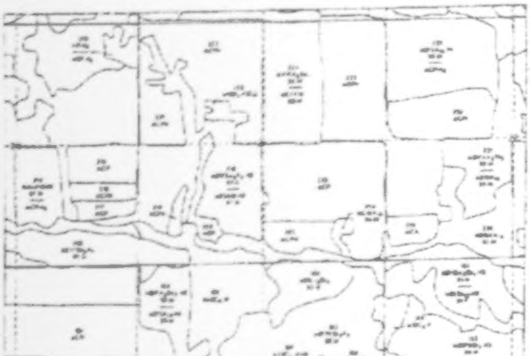

Figure 7

3. Results and Conclusions

The Automated Labeling System has been operational for several months and has allowed significant savings in manpower and cost in producing the labelled topographic maps. All processes, data transfers and error handling are controlled through ARC/INFO Macro Language (AML) and DCL commands and are executed either on batch processors or interactively. The CPU time requirements are not very significant and, on average, processing of a medium-sized coverage (≈500 polygons) takes less then 10 minutes of CPU time on a VAX 785 class minicomputer. The most serious problem that developed in the AVI project was the occurrence of very dense coverages with the number of polygons exceeding 950, and a very complex forest cover. In this case, when placing of labels inside the township borders is physically impossible, the Automated Labeling System identifies a high percentage of unplaceable labels (up to 15 %). The Land Information Services Division is currently analyzing the alternatives for labeling such maps and an upgrade to the Labeling System is to be implemented in the near future.

The current system provides a modularized solution that can be used for a wide areas of application through the manipulation of active parameters and software modules. The AVI specific conditions and requirements were used to optimize the functionality, structures and data flow. Different applications might require modifications or additions of some specific or more generalized routines.

The new modules could address the following concerns:

- Text label rotation. Coverages could be rotated before rasterization,
- Accommodation of other placement techniques as integer programming,
- Optimization techniques to define process parameters based on current data and system behaviour. These parameters could be utilized for each subsequent process,
- Name placement for different cartographic features,
- Modifications to user defined input and output requirements as creation of annotation coverages.

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Special Interest Group

[redacted]

Session G6
Issues in GIS Education

Issues to Consider When Developing or Selecting a GIS Curriculum

A One-year GIS Curriculum for Professional

Teaching GIS at the University of Idaho

GIS Education in Developing Countries - A Case Study from Tanzania

GIS'90 Symposium

Vancouver, British Columbia
March 1990

Issues to Consider When Developing or Selecting a GIS Curriculum

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Abstract
A number of model curicula have been developed for GIS. The various curicula designs represent different educational philosophies and different approaches to GIS. This presentation will introduce a number of GIS curicula, outlining issues that must be confronted when developing GIS programs. An attempt is made to match GIS curicula with GIS employment expectations. The paper should be of interest to those interested in enroling in GIS courses, and those confronted with the task of hiring GIS expertise.

1. Introduction

Following two decades of research and development, digital geographical information systems (GIS) have become operational and popularized throughout the 1980s. This popularization has placed increased pressure on universities and colleges to offer introductory and advanced courses covering GIS, as well as digital cartography and geographical information analysis (GIA).

Educational institutions have responded to this pressure in a number of different ways. Some university departments have incorporated GIS by simply changing the content of one or a number of existing courses without actually altering their existing curriculum structure. Other university departments have attempted to build entire new programs to meet demands, including the establishment of teaching laboratories. Some technical colleges have set up GIS training programs, and some institutions have gone so far as to establish interdisciplinary centres and programs specialising in GIS.

The experiences gained from the various attempts to incorporate GIS in teaching curicula have been discussed at a number of conferences and in workshops (Carter, 1985, 1987; Goodchild, 1985; Jenks, 1987; Nyerges and Chrisman, 1989; Parent, 1988 and Poiker, 1985). Last year, following a decade of experimentation, a number of model GIS curicula have been proposed.

Individuals practising resource management, municipal management, forestry or other careers that require the handling of land related information may be interested in taking a course or degree focusing on computer cartography or GIS, or may be confronted with the task of hiring GIS educated and/or trained people. The objectives of this paper, therefore, are to introduce and discuss a number of existing GIS curicula in order to give the reader a better understanding of educational products offered, and to introduce issues to be considered when making decisions which include educational program evaluation. The goal of the paper, therefore, is to raise awareness concerning issues of GIS education and training amongst those interested in advancing their GIS education, and amongst those contemplating hiring GIS expertise.

The remainder of the paper is structured as follows: To give the reader an opportunity to compare a number of GIS programs, the following section will introduce and discuss three GIS curicula developed. In order for the reader to evaluate the constraints under which a GIS program must operate, the next section will list the operational issues that must be considered when setting up such a program. This is followed by a discussion of GIS curicula in relation to expected GIS expertise.

2. Three GIS Curicula

2.1 Introduction

This section introduces the reader to three GIS curicula. An attempt was made to select curicula from programs reflecting different sizes of institutions and program design philosophies. Curicula selected are the NCGIA core curriculum proposed by the United States National Centre for Geographical Information Analysis and the GIS programs offered in the Department of Geography, the University of Washington, Washington and the Department of Geography, the University of Victoria, British Columbia.

2.2 NCGIA Curriculum Proposal

The National Centre for Geographical Information Analysis (NCGIA) some time ago recognized the need for a GIS core curriculum model. In 1988-89, using academic and private sector experts from around the world, NCGIA developed a set of course materials for a one year introductory curriculum in GIS. A draft version of the curriculum content is now complete, and is being tested by departments around the world (NCGIA 1989a,b and c). After a year of evaluation, the curriculum is to be revised over the summer of 1990, with final release scheduled for July 1990.

The philosophy underlying the core curriculum design is the recognition that GIS is still in its early stages of development, and that development to date has been driven by applications rather than theoretical aspects. The curriculum, therefore, has been designed to attempt to balance the needs of the job market and the need to educate and advance GIS users in theories of cartography and spatial analysis. The NCGIA curriculum shows strong ties between GIS and land information analysis (spatial analysis).

The NCGIA GIS course content is designed for instruction at the university upper division undergraduate level. It is a three course curriculum, each course consisting of 25 lectures. Topics covered are shown in Table 1. The first course functions to introduce students to hardware, software and operations of GIS, providing the essentials required by a beginning GIS technician. The remaining two courses are advanced, focusing on technical aspects and applied aspects respectively. The technical course is designed to explore areas related to the computer science and computer cartography roots of GIS. The applied course deals with applications, management, spatial analysis and spatial decision making. The idea underlying the core curriculum is for educators to teach the content in three consecutive courses as suggested by the NCGIA, or to select and integrate into an existing course structure a set of topics from the seventy-five lectures to suit the needs of individual institutions and departments.

2.3 University of Washington Curriculum Proposal

Nyerges and Chrisman (1989) have proposed a framework for a model curriculum in cartography and GIS, termed CAGIS, which was developed during discussions held when reorganizing the University of Washington's cartography program in the Department of Geography. Contrary to the NCGIA core curriculum, which shows close ties to spatial analysis, CAGIS is more closely tied to cartography, emphasising cartographic principles, computer cartography and programming.

Nyerges and Chrisman note that CAGIS breaks from the traditional approach to curriculum development along a linear sequence of courses aiming at continued knowledge

LECTURE #	TOPIC
I	INTRODUCTION TO GIS
1,2,3	Introduction
4,5,6	Hardware and Software Overview
7,8,9	Raster Based GIS
10,11	Data Acquisition
12,13	Nature of Spatial Data
14,15	Spatial Objects and Spatial Relationships
16-22	GIS Functionality
23,24	Raster/Vector Contrasts and Issues
25	Trends in GIS
II	TECHNICAL ISSUES IN GIS
26-29	Projections and Geocoding
30-34	Data Structure and Algorithms: Vector
35-37	Data Structure and Algorithms: Raster
38-42	Data Structures and Algorithms for Surface, Volumes and Time
43,44	Databases for GIS
45-48	Error Modelling and Uncertainty
49-50	Visualization
III	APPLICATION ISSUES IN GIS
51-53	Introduction to Application Areas and Techniques
54-57	Decision Making in a GIS Context
58-63	Project Lifecycle
64-65	The Multipurpose Cadastre
66-68	Impact of GIS Management Structures, Economics and Institutions
69,70	Database Design for GIS
71,72	Data Exchange and Standards
73,74	New Directions in GIS
75	Impacts of GIS

Source: Adapted from NCGIA, 1989a,b,c.

Table 1. NCGIA Core Curriculum Course Content

and skill refinement. Instead, their curriculum design is argued to adopt a modular matrix approach to increase flexibility. However, an examination of their curriculum proposal reveals that the concept of a linear course sequence is not lost in the modular matrix, given that an inspection of the modules allows one to identify logical course progression.

CAGIS is based on 11 courses, starting with an introductory second year undergraduate course, and ranging to advanced graduate courses. The course contents are shown in Table 2. A detailed examination and critique of the CAGIS curriculum proposal is beyond the length of this paper. It should suffice to observe here that Nyerges and Chrisman note that course 258 is designed as a general introductory course to GIS and cartography, that courses 360, 460 and 463 are designed to elaborate on concepts and principles while providing the student with some user experience, that courses 465, 563 and 565 are computer programming and system development oriented courses, and that courses 458, 520, 529 and 560 focus on system design and system use.

2.4 University of Victoria Curriculum

The teaching curriculum of the Department of Geography at the University of Victoria allows students to gain a specialization in GIS by taking a set of courses as outlined in Table 3. Pre-requisites to Geog. 428, the course specializing in

Topic	Course Number 258	360	458	460	463	465	520	529	560	563	565
Source Materials	1	2	3		4			2	2		
Data Collection	1	1	2	3		2					
Compilation & Integration	1	2	2	3	3			3			
Graphic Design Principles	2	3				3					4
Symbolization	2	3	2			4					
Map Production		1	1	2							
Cognition		2	2				3	3			4
Projections	1	2				3					
Coordinate Systems	1	2	2	2	3	3		3		3	
Generalization		2	2			3			4		
Map Typologies	1	2	3		3	4		2			
Spatial Reasoning				2	3		2		2	3	4
Processing 0/1/2/3d Data		1	1	2	3	4	2	2	3	4	3
Error and Consequences		1	3	1	2			1	2		
Data Structures		1	1	2	2	2	3		2	4	4
Data Models				1		2	2			3	3
Data Base Design		1		1	2	2		3			
Implementation in Society				1		1	2	3	3		
Algorithms & Programming				1	2	3	2		2	4	4
Knowledge- Based							2				3
System Integration						1		2			3

1: Exposure to topic
2: Principles behind topic
3: Master tools to address topic
4: Construct own tools for topic

Source: Nyerges and Chrisman, 1989.

Table 2. University of Washington Matrix of CAGIS Topics and Courses

GIS, are a background in statistical principles, an introductory knowledge of basic cartographic principles, and credits in an introductory mathematics and computer science course.

The courses listed in Table 3 cover the following materials. Geog. 321 introduces students to parametric and non-parametric statistics. Geog. 323 introduces students to map projections, coordinate systems, datum, directionality, spatial data, cartographic generalization, data reduction, map design, colour theory, typography and issues of professional conduct. Students interested in remote sensing as well as GIS are encouraged to take Geog. 322 followed by Geog. 422, an introductory and advanced course in air photo, remote sensing and digital terrain modelling. Geog. 428 is the Department's core GIS course. Students interested in using GIS for management decision making and planning also are strongly encouraged to take Geog. 426, a course in spatial analysis and decision making, as well as other courses in their area of research interest (resource management, urban studies, transportation, hydrology, geology, tourism, etc.). Students with a strong interest in cartography are encouraged to take Geog. 423, which covers contemporary research in cartography. Those with a special research interest in GIS that is of mutual interest to the GIS instructor(s) may also enrol in a special reading course, which is designed to allow the instructor and the student to develop a course content, assignments and evaluations to suit the specific research project.

The Department of Geography also has an active co-op program, and students with a GIS interest who meet the entrance requirements are encouraged to join the co-op, and to seek GIS working experience during their work terms. This option has proven of great benefit to both students and employers.

Year	Courses	Co-op
1st or 2nd Year	321 Introductory Statistics	Co-op Work Experience
2nd or 3rd Year	323 Introductory Cartography 322 Introduction to Air Photo and Remote Sensing	
3rd or 4th Year	423 Contemporary Issues in Cartography 426 Spatial Analysis 428 GIS 422 Remote Sensing 490 Special Reading Course	
Grad. Level	524 Seminar in Spatial Analysis 528 Seminar in GIS 590 Special Reading Course	

Table 3. University of Victoria GIS Curriculum

At the graduate level, students with an interest in GIS are encouraged to take seminar courses in GIS and spatial decision making, followed by a special reading course with the GIS instructor(s). The special reading course allows the student to assemble, compile and summarize literature of relevance to the student's thesis topic, as well as preparing a pilot project design. There exists an option for graduate co-op, but work term employment should be related directly to the student's research, and should not force the student to bias research conduct or findings.

3. Operational Considerations

3.1 Introduction

It is generally recognized that a company, municipality or government department's entry into the field of GIS is expensive, and that entry involves operational and administrative adjustments. All too often, however, implications of cost and administration are ignored at the outset, leading to potential conflict, bottlenecks and struggle down the road. This holds true, too, for educational institutions. An educational institute wishing to respond to the demand for GIS education and training therefore should confront a number of operational considerations at the outset. Issues to be addressed have been divided below into institutional and infrastructural considerations.

3.2 Institutional Considerations

Institutional considerations should be addressed by both the institution contemplating a GIS curriculum initiative, and the individual, group or department spearheading that initiative. The two groups should reach agreement on a number of issues before proceeding with any initiative implementation. The issues are as follows:

- Identify the degree of commitment and support, in principle, on both sides to develop a program in GIS,
- Determine the size and scale of the program,
- Allocate necessary authorities and responsibilities,including clear identification of channels of reporting and administrative structure,
- Establish time frames for program development,
- Secure financial commitments,
- Define manpower commitments,
- Identify physical plant commitments,
- Reach agreement on a mechanism for evaluating an individuals' efforts and time spent initiating a GIS program, and agreement on implications to career advancement and financial reward.

Lack of a common vision, and lack of an understanding at the outset with respect to the above listed commitments, costs and reward mechanisms, invites trouble. A number of educational GIS programs have developed, or are being developed, where agreement on the above issues was not reached. This has lead, in many cases, to mistrust, ill feelings, and sometimes failure.

3.3 Infrastructural Considerations

It is conceivable that a course in GIS could be taught without access to a laboratory containing GIS equipment. However, it is highly unlikely that a GIS curriculum will be successful and competitive without access to a teaching laboratory for hands on practica. A number of infrastructural considerations, therefore, should be addressed before committing to a GIS curriculum. These considerations can be divided into issues of laboratory space and furnishing, hardware, software and humanware. Each is discussed below.

The norm for educational institutes, as is true for most other institutions, appears to be to wage continual battles over access to physical space. One of the first steps, therefore, must be to secure adequate space to house a number of instructional GIS, including input and output peripherals. The logical next step is to secure funds to furnish this facility, including the acquisition of hardware and software. It is of interest to note that surprisingly little has been written to assist faculty in making decisions concerning room design and furniture selection. However, design issues, including ergonomics, light reflectance, dust problems, air conditioning, static, noise, visual appeal, etc., should not be ignored when designing a laboratory.

Two considerations all too often forgotten when deciding on hardware and software for a teaching laboratory concern maintenance costs and the rapid advances in GIS technology. Hardware and software vendors charge varying rates for maintenance and support of their products. The result is that, often, a product that appears cheap to acquire turns out to be so expensive to maintain that service contracts cannot be honoured, leading to costly headaches when equipment malfunctions or software proves to be not user-friendly. Also, one of the realities of GIS is that software and hardware are out-of-date the day they are ordered. Mechanisms must therefore be put in place to ensure that operating budgets allow for periodic replacement of outdated equipment.

The last issue concerns GIS curriculum support staff. Faculty often initiate GIS programs without support staff, managing, maintaining and operating the facility on their own. They subsequently find it difficult to justify to their superiors the need for support staff, given that the lab has been operating without it. At the same time, they have a difficult time justifying why they have been neglecting other duties because of time spent maintaining the facility. Educational institutes, as well as faculty, do not benefit from teaching staff spending large proportions of their day unpacking computers, installing and maintaining software, dusting computer screens and trouble-shooting system failures. Support staff should therefore be agreed upon and hired at the outset.

To conclude, a successful and competitive GIS curriculum will most likely require a teaching laboratory. Faculty expected to set up these laboratories should ensure that they have sufficient commitment and support to set up and maintain such a facility, and that their career advancement is not adversely affected because of time spent setting up such a laboratory. Faculty must also recognize that the size and scale of a teaching laboratory will determine the size and extent of the GIS curriculum it supports. Our experience has shown that a laboratory with ten GIS can barely support two concurrent courses, each with an enrolment ceiling of 20 students, in spite of laboratory opening hours of up to 14 hours a day. A realistic curriculum, therefore, must accommodate constraints of laboratories, faculty and support staff.

4. Discussion

As was noted above, individuals practising resource management, municipal management, forestry or other careers that require the handling of land related information may be interested in taking a degree or course focusing on GIS, or may be confronted with the task of hiring GIS educated and/or trained people. The question that must be confronted is which program to enrol in, or which program to hire from.

Program selection will depend on a number of constraints and variables, some of which will have little to do with the actual quality or content of a GIS curriculum offered. Constraints such as geographical proximity (access), registration cost, the time the program is scheduled, and barriers to enrolment enforced by entrance requirements or enrolment ceilings often will override considerations of curriculum content and program reputation. However, this paper will address only the latter.

One of the first questions to pose when evaluating amongst different GIS curicula is to examine the nature of the GIS expertise that is desired. This requires a break-down of GIS literate individuals into distinguishable groups. Marble (1979) notes that there exist two types of GIS expertise, created by two educational program structures, one leading to expertise as a GIS user/analyst, the other leading to expertise as a GIS developer/programmer. Parent (1988) distinguishes between the casual GIS user, the GIS user specialist, the GIS developer and the GIS manager. The National Centre for GIA (1989a) identifies three groups, the GIS operators, the GIS managers, and the planner/ analyst using GIS. The above suggests that there exists a four fold division as follows:

- Technician/ operator,
- System developers/ programmers,
- Analyst/ planner,
- Manager/ program coordinator.

Job descriptions calling for a GIS technician or a GIS operator are best served by individuals who have received technical GIS training through a course offered by a regional college or a software vendor. However, individuals hired should bring along a basic knowledge of cartographic principles offered in an introductory university cartography course. Cartographic principles should include map projections, coordinate systems, generalization, symbolization, colour theory, typography and map design. Digital map products displayed over the last few years suggest that cartographic knowledge has been neglected as a hiring criteria when employing GIS technicians, something that has not helped the reputation of digital cartography.

Job descriptions that require software development or software customizing skills are best served by an individual with a rigorous training in computer sciences and an education in GIS as a secondary specialization. The ideal applicant would be a student with a major in computer sciences and a minor in geography, specializing in cartography and GIS. The applicant should have participated in courses emphasizing data structures, data models, algorithms, system integration, man-machine interaction and contemporary programming issues including artificial intelligence, knowledge-based programming and parallel processing.

Job descriptions that require an individual to use GIS to analyze land related data, and to conduct spatial planning are best served by an applicant with a rigorous education in spatial analysis, spatial statistics and spatial reasoning, including considerable exposure to courses discussing errors arising from data accuracy, precision and processing as well as error consequences. Potential job candidates should also bring with them a sound knowledge of the appropriate field of application, such as forestry, soil sciences, geology, municipal planning, etc

Individuals hired to manage or coordinate a GIS facility are required to have an introductory knowledge of all facets of GIS. This includes some experience with the technical skills required for GIS operation. The latter is important since managers, all too often, do not understand the daily problems encountered on the shop floor when entering and routinely processing geographical information, leading to unnecessary misunderstandings and friction. Managers should have participated in GIS courses emphasising system evaluation, system implementation, system integration and system lifecycle.

5. Summary

This paper has set out to raise awareness concerning issues of GIS education and training amongst those interested in advancing their GIS education, and amongst those contemplating hiring GIS expertise. The paper should have demonstrated that different GIS programs emphasize different aspects of GIS. It should have become clear that some programs focus on technical skills, some emphasize the cartographic roots of GIS, some specialize in the analysis and interpretation of geographical information, some focus on computer programming and system development, while still others emphasize managerial issues. It was argued that GIS programs are constrained by a number of variables, most noticeably the number of faculty available to support the program and the resources available to establish teaching and research laboratories. However, it should be kept in mind that program content ultimately reflects the background and research interests of the faculty teaching the curriculum.

Cartography and spatial analysis, the basic fundamentals of GIS, have their roots in geography. However, the study of GIS, by application, is interdisciplinary in nature. Those involved in GIS therefore frequently will require multidisciplinary training and joint degrees. Individuals with a sound knowledge of an area of application without proper education in GIS are as unsatisfactory and potentially misdirected as are those with a sound education in GIS without the necessary body of knowledge in the application field.

Successful participation in GIS implies the assemblage of a team that has appropriate levels of training and education. Those in charge of hiring must look beyond software and hardware training experience to individuals educated in different aspects of GIS. Without a soundly educated team, Nyerges and Chrisman correctly note that users of computer cartography and GIS will perhaps only make bigger and faster mistakes than ever before.

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A One-year GIS Curriculum for Professionals

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Abstract
The British Columbia Institute of Technology has begun a comprehensive educational and training plan in Geographic Information Systems (GIS). This plan embraces both full-time and part-time courses of studies, and is aimed at preparing potential users of GIS in government and industry with the tools required to manage and utilize GIS technology effectively. The curriculum, courses, and facilities are described, the first year of full operation is reviewed and evaluated, and revisions and future possibilities are outlined.

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Teaching GIS at the University of Idaho

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Abstract
GIS Primer, a university-wide, introductory GIS course, has been offered at the University of Idaho for two years in response to the growing needs for GIS specialists. It is team-taught by instructors from Landscape Architecture and Geography. Multi-disciplines are represented in the student body: Geography, Landscape Architecture, Forestry, Soil Science, Agriculture and others. The course includes lectures, hands-on laboratory exercises, and guest lectures by several GIS experts in natural resource management, and urban and regional planning. Once students complete the GIS Primer, they may enrol in advanced GIS courses in various disciplines. Advanced courses are currently taught in Landscape Architecture and Geography. Hands-on laboratory work uses advanced ARC/INFO GIS software in these courses.

Introduction

In 1987, a multi-disciplinary committee was convened to address the need for an introductory course for GIS at the University of Idaho. The main goal of this committee was to reorganize the GIS related courses on campus and to address the growing needs for a university-wide, introductory course which was aimed at non-technical students from a wide variety of disciplines. Prior to this endeavor, a few GIS-related courses had been taught in various disciplines at the University: In Geography, a course was taught on the University of Idaho IBM mainframe, while in Forestry, a remote sensing course was offered. In Landscape Architecture, a computer-aided regional land planning course was taught using a mini-based GIS. GIS courses had been taught at the senior and graduate levels, therefore the old GIS curricula were addressing only a small group of students interested in the GIS technologies. There was an urgent need to expand the student base and to promulgate the emerging GIS technologies among undergraduate students. Eventually, this committee effort resulted in an upper undergraduate level course which is to teach the basic principles associated with the GIS technologies, as well as, to provide the students with hands-on experience on PC-based GIS software.

This 'GIS Primer' course has been offered for two years, and over-all results are encouraging. The number of students enroled in the class rose from 20 to 32 this year, and it is expected to grow as more students show interest in the rapidly changing GIS technologies. As anticipated, the student body represents multi-disciplines, for example, Geography, Landscape Architecture, Agriculture, and Forestry; and the current trends indicate more students from additional disciplines will be involved in GIS in the future.

The objective of this paper is to review the progress made during the past two years and address some of the observed issues. Our multi-disciplinary approach to teaching GIS presented unique opportunities, as well as, some interesting problems which we are determined to solve in our future course offerings. It is hoped that cooperation and better coordination among various disciplines in teaching GIS will benefit students and would lead to a better understanding of GIS and its surrounding issues.

Course Content

The course is primarily organized in three segments: lectures, guest lectures, and hands-on laboratory exercises. Approximately 50% of class time is devoted to lectures with topics including geographic referencing systems, data base design, data entry, spatial analysis and modeling, hardware and software trends, and GIS history. The National Center for Geographic Information and Analysis (NCGIA) curriculum was introduced for the first time to the Primer class in 1989; however, for the most part it did not 'fit' to our course sequence and content. This was because there were too many chapters to cover in a semester and the instructors felt that some were inadequate. With much modification and many deletions, the instructors of the class adopted a few relevant chapters from the NCGIA curriculum.

During the past two years, the class hosted 10 individuals from several government agencies and corporations. Our guest lecturers provided our students with the real life pictures of GIS applications, and therefore very invaluable insight into the issues in GIS operations. The organizations represented include U.S. Forest Service, Bureau of Land Reclamation, Idaho Department of Transportation, Washington Department of Natural Resources, County of Spokane, City of Boise, Boise Cascade Corporation, Potlatch Corporation, Dames and Moore, and GGI. We will continue encouraging the cooperation between GIS professionals and the academic world, as it is very important to involve professionals representing multi-disciplines into our educational process, particularly in light of the fact that GIS is a tool which can be used in numerous disciplines.

The laboratory segment uses a hands-on approach by utilizing PC-based GIS software named GIX developed by Professor Otawa as an instructional tool. The hands-on laboratory exercises focus on various GIS concepts such as overlaying, buffering, query, recoding, classifying, etc. Each command in GIX represents a significant concept of GIS. There are approximately 50 major commands, and students are expected to experiment with all of them through a series of assigned exercises. These commands range from digitizing polygons, lines and points, to map and attribute display, and to a variety of geographic data analysis commands typically found in a raster-based GIS on the market. Once this phase is complete, simple suitability modeling techniques are presented. Instructors regularly require a final project where a student selects and defines his/her own problem and attempts to solve it with GIX. This process involves digitizing of map layers, editing, analysis, printing and report production; and generally, it requires approximately 2 to 3 class weeks to complete the project. This strategy has proven to be a very successful teaching method, since it ascertains student involvement in the learning process. Traditional lecturing tends to overlook this aspect of teaching, and supplementing it with non-traditional, hands-on exercises tremendously enhances students' educational opportunity since GIS forces students to think. This learning motivation is initiated by the student and is therefore called 'learner centeredness'

GIX was designed to promote learner centeredness. Because of its simple pull-down menu system, many first-time users find it reasonably easy to operate once the concept for each command is explained in detail. Its error detection mechanism ensures anticipated input from the user, although much has to be improved. Almost any conceivable type of input error can be expected by the first-time user of GIS, and experience has shown it is extremely difficult to detect those potential errors.

GIX is a family of software routines primarily developed for the IBM PC, XT, AT, PS/2 and compatibles running under MS-DOS and, for the most part, is written in the ANSI-standard C language. The PC environment provides educators with effective instructional tools, since there are a number of PCs readily accessible by students and their operation is easily understood. In addition, their prices are rapidly falling, enabling students to purchase their own PC. The combination of these factors increases their hands-on opportunities, thus helping them learn the concepts inherent in GIS at their own pace.

GIX uses 8-byte, double precision data for both attribute and coordinates, thereby ensuring relatively accurate results in computations. A system with 640K of conventional memory could accommodate a 200 by 200 matrix, while 2MB of EMS memory would allow a matrix of 512 by 512, or larger. Additional EMS memory allows an even larger data matrix. Two data formats are available in Version 1.0, GDF and DBF. The former is unique to GIX and is comparable to individual map layers, for example, soils and vegetation types. Because of the simplicity in data structure, it employs a typical raster or grid-cell format with the double-precision data assigned to each cell as attributes. The latter is introduced to provide dBASE file compability. Once all the map layers are digitized for the region of interest, they can be combined or 'packed' to create a DBF file for data analysis. With this capability, very complex queries can be performed on the existing data base using the Boolean operators — AND, OR, and XOR. All of these functions combined make GIX a true GIS equipped with both mapping and relational data base capabilities. Additional descriptions of GIX functionalities can be found in the papers previously published elsewhere.

Advanced GIS Courses

Once students gain a good understanding of GIS in the 'GIS Primer' course, they may enrol in advanced GIS courses offered in various disciplines on campus. Two are currently taught; GEOG 460 (Geographic Information Systems) and LARCH 490 (Computer-aided Regional Landscape Planning). The former focuses on the theoretical aspects of GIS, while the latter is more oriented towards applications of GIS to land planning. Both employ one of the state-of-the-art systems, ARC/INFO.

Observations

This new course has so far provided our students with great learning opportunities; however, there have been two major issues observed during the past two years. First, GIS Primer is jointly taught by two departments —Geography and Landscape Architecture. These two disciplines have different interest in GIS and differing approaches to teaching. Geography is primarily interested in the theoretical aspects of GIS, while Landscape Architecture is more application oriented, i.e., using GIS as a tool for land planning and management. The former focuses on lecturing as a prime mode of learning, whereas the latter often uses a studio or laboratory. Many lecture topics must be covered from geography's stand point and also much to cover for hands-on instructions from the landscape architectural positions. A 3-credit (semester) course meets three hours per week, i.e., 51 hours per semester. This amount of contact time is not enough to satisfy both discipline's needs in teaching GIS. This may be advised for other GIS curricula such as the one NCGIA will be proposing in the near future. Our course content requires a more narrow focus and priority settings on lecture topics and laboratory exercises. More discussions should be pursued on the class content of the absolute minimum which should be covered during one semester.

Secondly, there has not been enough equipment to accommodate our students. For example, 32 students were enroled in GIS Primer during the 1989 Autumn Semester. Our laboratory is currently equipped with 10 IBM-PC ATs which are shared by 300 other students. Although the laboratory is open from 8:30 a.m. to 11:00 p.m. 7 days a week, accessibility to these systems was quite limited. If a GIS course is to address a wide range of disciplines and students, their access to GIS hardware should be easily available and should not be hindered by the lack of equipment.

Conclusion

Our inter-disciplinary approach to teaching GIS has presented a great potential, as well as some problems. Overall, our students benefitted from the diversity of the instructors' backgrounds. With the additional efforts in solving the above-mentioned problems, the GIS Primer course will further improve. As stated, our current curriculum should be modified or fine tuned to fit into the over-all instructional context at the University of Idaho. The proposed NCGIA curriculum will still be a model and will require much modification for adaptation to the University of Idaho curriculum. Additionally, more personal systems are needed to accommodate the heavy demand from our students. The hands-on exercises should be an integral part of GIS courses and therefore these systems are the basic necessity for instructions.

The GIX Primer course provides the students with the fundamental knowledge and skills necessary to apply GIS to various problem-solving. If a student wishes to acquire advanced knowledge and training in GIS, the University offers advanced GIS courses as electives. It is expected that the two-tier approach to teaching GIS will prepare our graduating students with a sufficient base for their prospective GIS-related positions.

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GIS Education in Developing Countries - A Tanzanian Example

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Abstract
There are problems with the successful application of GIS in the management of forests in developing countries, not the least of which is the shortage of adequately trained personnel. This paper considers these problems with special emphasis on the case of Tanzania.